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STOCK STATUS OF CHENA RIVER ARCTIC GRAYLING¹

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TABLE OF CONTENTS

	<u>Page</u>
LIST OF TABLES.....	ii
LIST OF FIGURES.....	iii
LIST OF APPENDICES.....	iv
ABSTRACT.....	1
INTRODUCTION.....	2
Background.....	2
Stock Assessment Goals and Objectives.....	5
METHODS.....	6
Sampling Gear and Techniques.....	6
Population Abundance.....	6
Lower Chena River.....	8
Upper Chena River.....	11
Age and Size Composition.....	13
Lower Chena River.....	13
Upper Chena River.....	14
Survival and Recruitment.....	16
Historic Data Summaries.....	17
RESULTS.....	17
Lower Chena River.....	17
Upper Chena River.....	26
Chena River.....	26
DISCUSSION.....	32
ACKNOWLEDGEMENTS.....	35
LITERATURE CITED.....	35
APPENDIX A (HISTORIC SUMMARY OF ARCTIC GRAYLING RESEARCH IN THE CHENA RIVER).....	41

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Summary of total angling effort and Arctic grayling harvest on the Chena River, 1977-1988.....	3
2. Summary of sample area abundance estimates of Arctic grayling (≥ 150 mm FL) in the Lower Chena section of the Chena River, 10 through 20 July, 1989.....	19
3. Estimated abundance of Arctic grayling (≥ 150 mm FL) in the lower 72 kilometers of the Chena River (Lower Chena section), 10 through 20 July, 1989.....	21
4. Estimates of age composition and abundance by age with standard errors from Arctic grayling (≥ 150 mm FL) captured by pulsed-DC electrofishing in the Lower Chena section of the Chena River, 10 to 20 July, 1989.....	23
5. Summary of Relative Stock Density (RSD) indices of Arctic grayling (≥ 150 mm FL) captured in the Lower Chena section of the Chena River, 10 through 20 July, 1989.....	25
6. Capture probabilities and estimated abundance in two length categories used for population estimation of Arctic grayling (≥ 150 mm FL) in the Upper Chena section of the Chena River, 24 through 27 July, 1989...	28
7. Estimates of adjusted age composition and abundance by age class with standard errors for Arctic grayling (≥ 150 mm FL) captured by pulsed-DC electrofishing from the Upper Chena section of the Chena River, 24 through 27 July, 1989.....	29
8. Summary of Relative Stock Density (RSD) indices of Arctic grayling (≥ 150 mm FL) captured in the Lower and Upper Chena sections, and the Chena River, 1989....	30
9. Estimates of age composition and abundance by age with standard errors for Arctic grayling captured by pulsed-DC electrofishing from the Lower and Upper Chena sections and the Chena River, 1989.....	31
10. Summary of population abundance, annual survival (%), annual recruitment, and standard error estimates during 1986-1989, and forecast recruitment during 1990 and 1991 for Arctic grayling (\geq age 3) in the lower 152 km of the Chena River.....	33

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. Annual harvests of Arctic grayling in the Chena River and in the entire Tanana drainage excluding the Chena River, 1977-1988 (taken from Mills 1979-1989).....	4
2. The Chena River below the Moose Creek Dam complex (Lower Chena River section).....	7
3. The Chena River above the Moose Creek Dam complex (Upper Chena River section).....	9
4. Cumulative distribution functions (c.d.f) of lengths of Arctic grayling marked versus lengths of Arctic grayling recaptured for four 3.2-km sample areas of the Lower Chena section of the Chena River, 10 through 20 July, 1989.....	18
5. Age compositions of Arctic grayling sampled from each of four 3.2-km sample areas of the Lower Chena section of the Chena River, 10 through 20 July, 1989 (N = sample size).....	22
6. Size compositions of Arctic grayling sampled from each of four 3.2-km sample areas of the Lower Chena section of the Chena River, 10 through 20 July 1989 (N = sample size; S = stock (150 to 269 mm FL), Q = quality (270 to 339 mm FL), P = preferred (340 to 449 mm FL), M = memorable (450 to 559 mm FL), and T = trophy (greater than 559 mm FL).....	24
7. Cumulative distribution functions (c.d.f.) of lengths of Arctic grayling marked versus lengths of Arctic grayling recaptured (A) and versus lengths of Arctic grayling examined for marks (B) for the Upper Chena section of the Chena River, 24 July through 3 August, 1989.....	27
8. Abundance (A) and survival (B) of Arctic grayling (\geq age 3) in the the lower 152 km of the Chena River, 1986-1989.....	34

LIST OF APPENDICES

<u>Appendix</u>	<u>Page</u>
A1. Source citations for Federal Aid and Fishery Data Reports used for data summaries, 1955-1958 and 1967-1989.....	42
A2. Chena River study sections used from 1968 to 1985.....	43
A3. Summary of population abundance estimates of Arctic grayling (≥ 150 mm FL) in the Chena River, 1968-1989...	44
A4. Summary of Arctic grayling creel census on the Chena River, 1955-1958, 1967-1970, 1972, and 1974-1989.....	46
A5. Summary of age composition estimates of Arctic grayling in the Chena River stock, 1967-1969 and 1973-1989.....	47
A6. Summary of mean length at age estimates of Arctic grayling from the Chena River, 1967-1969 and 1973-1989.....	48
A7. Summary of Relative Stock Density (RSD) indices of Arctic grayling (≥ 150 mm FL) captured by electrofishing from the Chena River, 1972-1989.....	49
A8. Parameter estimates and standard errors of the von Bertalanffy growth model for Arctic grayling from the Chena River, 1986-1988.....	52

ABSTRACT

Arctic grayling *Thymallus arcticus* were captured by pulsed direct-current electrofishing in two sections of the lower 152 kilometers of the Chena River in 1989. Stock status of Chena River Arctic grayling was described by population abundance, age composition, size composition, recruitment, and survival estimates. Estimated population abundance in the lower 72 kilometers of the Chena River (Lower Chena section) was 4,165 Arctic grayling greater than 149 millimeter fork length; and was 14,863 Arctic grayling greater than 149 millimeter fork length in the upper 80 kilometers of the Chena River (Upper Chena section). Age three and age six Arctic grayling were strongly represented in both sections of the Chena River, while age two Arctic grayling were relatively abundant in the Lower Chena section. Size composition varied among river sections, although stock size (less than 270 millimeter fork length) Arctic grayling were most numerous in both river sections. Annual recruitment between 1988 and 1989 was 4,332 Arctic grayling and annual survival during this period was 58.7 percent. Although annual survival rate has increased during the last three years, further increases in annual survival are not anticipated under the existing regulatory structure. If annual recruitment remains at currently low levels, additional regulatory measures may be warranted to prevent short term depletion of the Chena River stock.

KEY WORDS: Arctic grayling, *Thymallus arcticus*, electrofishing, population abundance, age composition, size composition, Relative Stock Density, recruitment, survival rate, management, historic data summaries, Chena River.

INTRODUCTION

Background

The Chena River supports one of the largest Arctic grayling fisheries in North America. For the ten year period from 1979 to 1988, the Chena River produced an average annual sport harvest of 17,321 Arctic grayling in 26,339 man-days of angling effort (Table 1). As recently as 1984, annual harvests had exceeded 20,000 fish and 30,000 man-days of effort and harvests of Arctic grayling from the Chena River comprised a substantial portion of total Arctic grayling harvests in the Tanana River drainage (Figure 1). However, the status of this fishery has changed since 1984. Recreational harvest of Arctic grayling has declined to historic low levels. Harvest decreased 76% from 1984 to 1985, although angling effort had decreased only 39% (Table 1). Angling effort returned to an average level in 1986, but harvest remained below 10,000 fish. Concomitant with the declining recreational fishery was the decline in Arctic grayling population abundance. Stock assessment projects during 1986 (Clark and Ridder 1987b) and 1987 (Clark and Ridder 1988) documented a decline in population abundance of 49% between these two years. Poor recruitment was the probable cause for a decline in abundance (Holmes 1984; Holmes et al. 1986).

During winter of 1986, fishery managers were scheduled to present stock status data (Clark 1986) on the Chena River fishery to the Alaska Board of Fisheries. The Board of Fisheries meeting adjourned before the data could be presented. In spring of 1987, increased concern for the health of the Chena River stock prompted fishery managers to process emergency regulations to reduce harvest. These emergency regulations were:

- 1) closure of the fishery until the first Saturday in June;
- 2) a 12 inch (305 mm) minimum length limit; and,
- 3) restriction of terminal gear to unbaited artificial lures.

These emergency regulations were made permanent regulations in the summer of 1987. During the winter of 1987, fishery managers presented stock status and regulatory concerns to the Alaska Board of Fisheries (Clark 1987). The emergency regulations imposed in spring of 1987 were adopted and amended. The new permanent regulations were:

- 1) catch-and-release fishing from 1 April to the first Saturday in June;
- 2) a 12 inch (305 mm) minimum length limit from the first Saturday in June until 31 March;
- 3) restriction of terminal gear to unbaited artificial lures only throughout the Chena River, and bait fishing allowed downstream of the Moose Creek Dam with hooks having a gap larger than 0.75 inch (19 mm);

Table 1. Summary of total angling effort and Arctic grayling harvest on the Chena River, 1977-1988^a.

Year	Lower Chena River ^b		Upper Chena River ^c		Entire Chena River	
	Angler-days	Harvest	Angler-days	Harvest	Angler-days	Harvest
1977 ^d	---	---	---	---	30,003	21,723
1978 ^d	---	---	---	---	38,341	33,330
1979	9,430	11,290	8,016	11,664	17,446	22,954
1980	13,850	18,520	10,734	16,588	24,584	35,108
1981	11,763	10,814	10,740	13,735	22,503	24,549
1982	18,818	11,117	15,166	12,907	33,984	24,024
1983	17,568	7,894	16,725	10,835	34,293	18,729
1984	20,556	13,850	11,741	12,630	32,297	26,480
1985	11,169	2,923	8,568	3,317	19,737	6,240
1986	18,669	4,167	10,688	3,695	29,357	7,862
1987 ^e	12,605	1,230	10,667	1,451	23,272	2,681
1988 ^{e,f}	16,244	2,686	9,677	1,896	25,921	4,582
Averages ^g	15,068	8,449	11,272	8,872	26,339	17,321

^a Taken from Mills (1979-1989).

^b Lower Chena River is from the mouth upstream to 40 km Chena Hot Springs Road (Mills 1988).

^c Upper Chena River is the Chena River and tributaries accessed from the Chena Hot Springs Road beyond 40 km on the road (Mills 1988).

^d Angler-days and harvest are computed for the Chena River and Badger Slough.

^e Special regulations were in effect during 1987 and 1988. These regulations were: catch-and-release fishing from 1 April until the first Saturday in June; a 305 mm (12 inch) minimum length limit; and, a restriction of terminal gear to unbaited artificial lures.

^f In addition to the special regulations, a catch-and-release area was created on the Upper Chena River (river km 140.8 to 123.2).

^g Averages are for 1979 through 1988 only.

Harvest of Arctic Grayling

100,000

80,000

60,000

40,000

20,000

0

1977

1979

1981

1983

1985

1987

Year

▨ Chena R. ▩ Tanana drainage

Figure 1. Annual harvests of Arctic grayling in the Chena River and in the entire Tanana drainage excluding the Chena River, 1977-1988 (taken from Mills 1979-1989).

- 4) catch-and-release fishing year around from river kilometer 140.8 downstream to river kilometer 123.2; and,
- 5) reduce the possession limit from 10 to 5 fish (Tanana drainage-wide regulation).

The regulations adopted by the Board of Fisheries in winter of 1987 were the first changes in Arctic grayling management since 1975, when the daily bag limit was decreased from 10 to 5 fish. Evaluation of the effects of new regulations on the Arctic grayling stock and recreational anglers was begun in 1987.

Stock Assessment Goals and Objectives

Much of what is known about Arctic grayling population dynamics comes from research conducted in the Tanana drainage and particularly the Chena River. Stock status of Arctic grayling in the Chena River is measured on an annual basis, primarily during late June and all of July. Population abundance, age composition, size composition, recruitment, and survival are estimated each year to determine the health of the stock. The long-term goals of stock assessment on the Chena River are to:

- 1) accurately and precisely describe the stock status of Chena River Arctic grayling on an annual basis;
- 2) use stock status data in models that predict the consequences of regulatory actions; and,
- 3) provide fishery managers with stock status data and model results so that informed management decisions can be made.

As stock status data are collected over a series of years, predictive models can be created to determine the effects of sport fishing on the Arctic grayling stock. The success of modelling efforts is dependent on the accuracy and precision of stock status data. If the first two goals are successful, the third goal is essentially fulfilled. Therefore, attainment of the first goal is essential to the management process and future health of the stock.

As part of attaining the first stock assessment goal, the objectives of the 1989 research efforts were to:

- 1) estimate the absolute abundance of Arctic grayling greater than 149 mm fork length (FL) in the lower 152 km of the Chena River;
- 2) estimate the age composition of Arctic grayling in the lower 152 km of the Chena River; and,
- 3) estimate Relative Stock Density (RSD) of Arctic grayling in the lower 152 km of the Chena River.

In addition to these primary assessment goals, recruitment of new fish to the stock and the annual survival rate of the stock were estimated.

METHODS

Sampling Gear and Techniques

All sampling was performed with a pulsed-DC (direct current) electrofishing system mounted on a 6.1 m long river boat as previously described by Lorenz (1984). Input voltage (240 VAC) was provided by a 3,500 W single-phase gas powered generator (Homelite Model HG3500). A variable voltage pulsator (Coffelt Manufacturing Model VVP-15) was used to generate output current. Anodes were constructed of 12.7 mm diameter and 1.5 m long twisted steel cable. Four anodes were attached to the front of a 3 m long "T-boom" attached to a platform at the bow of the river boat. The aluminum hull of the river boat was used as the cathode. Output voltages during sampling varied from 200 to 300 VDC. Amperage varied from 2.0 to 3.5 A. Duty cycle and pulse rate were held constant at 50% and 60 Hz, respectively. These operating characteristics were presumed to minimally affect Arctic grayling survival during mark-recapture experiments. Water conductivity ranged from 85 μ S to 125 μ S (at 25°C) during electrofishing.

Sampling was conducted along the banks of the Chena River. The electrofishing boat was directed downstream along each bank, collecting all Arctic grayling seen, when possible. Captured Arctic grayling were held in an aerated holding tub to reduce capture related stress. The selected areas of the Chena River were sampled no more than once per day to prevent changes in capture probabilities of marked fish (Cross and Stott 1975). Each Arctic grayling was measured to the nearest 1 millimeter FL. A sample of scales was taken from the preferred zone¹ of each newly captured Arctic grayling. Arctic grayling greater than 149 mm FL were marked with individually numbered Floy FD-68 internal anchor tags inserted at the base of the dorsal fin. The tip of the right pelvic fin was removed to identify marked fish in case the numbered tag was shed. If any captured Arctic grayling exhibited signs of injury or imminent mortality, they were immediately sacrificed. Sacrificed fish were examined for sex and maturity.

Population Abundance

The abundance of Arctic grayling greater than 149 mm FL was estimated by mark-recapture techniques in the lower 152 km of the mainstem Chena River. Two sections of the Chena River were delineated for separate estimation experiments. Delineation of the Chena River was necessary because Tack (1980) and Clark and Ridder (1988) found increasing density of Arctic grayling with increasing distance upstream. Based on differences in population density from downstream to upstream areas of the Chena River, the lower 152 km of the Chena River is divided into Lower and Upper sections for estimating abundance and age composition. Downstream from the Moose Creek Dam complex to the mouth of the Chena River was designated the Lower Chena River (72 km long; Figure 2).

¹ The preferred zone for Arctic grayling is an area approximately six scale rows above the lateral line just posterior to the insertion of the dorsal fin.

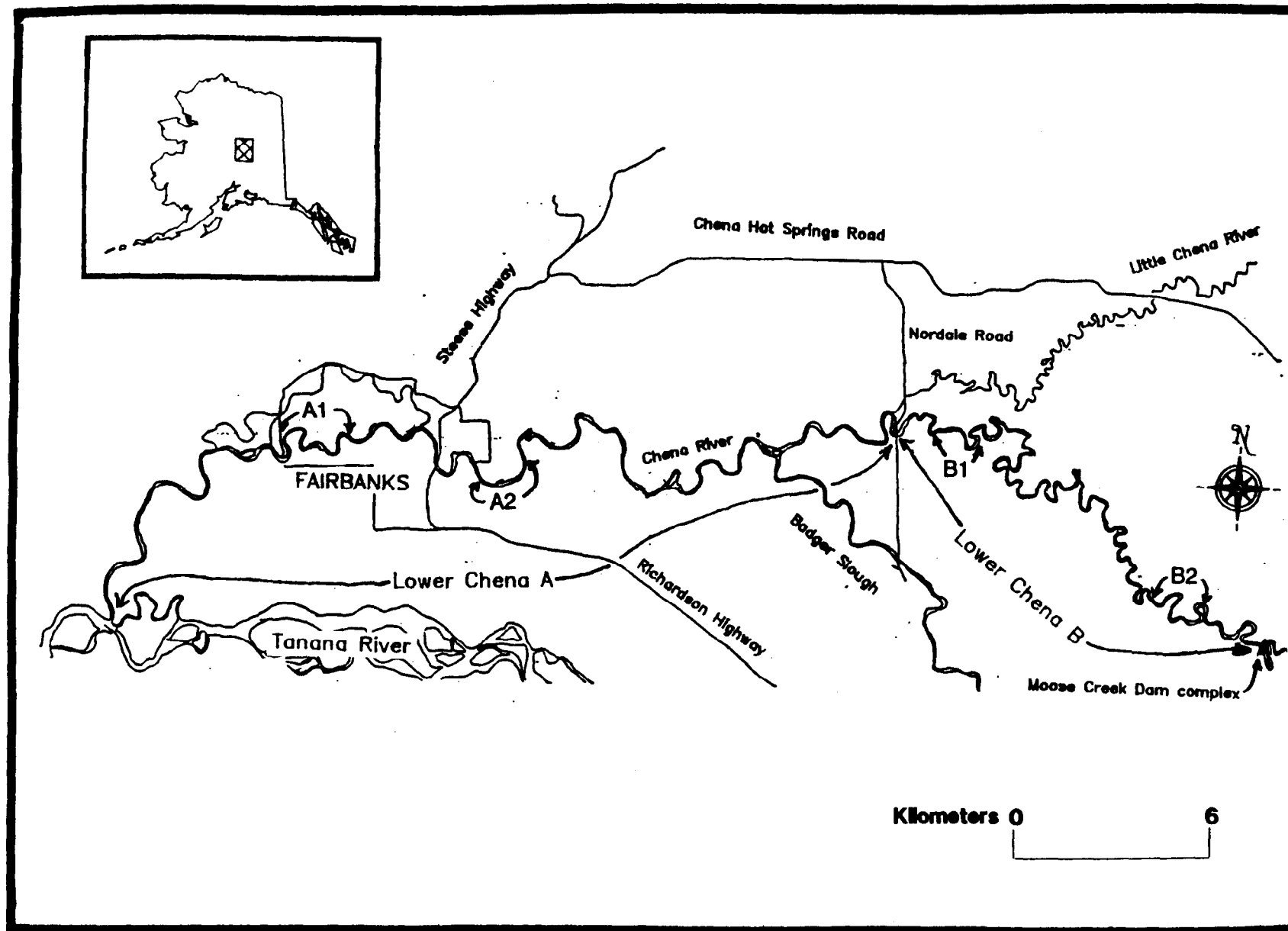


Figure 2. The Chena River below the Moose Creek Dam complex (Lower Chena River section).

Upstream from the dam to the second bridge on the Chena Hot Springs Road (kilometer 63.2) was designated the Upper Chena River (80 km long; Figure 3). Population abundance estimates pertain only to these two sections of the Chena River, excluding Badger Slough, the Little Chena River, and the South Fork of the Chena River.

Lower Chena River:

Population abundance in the Lower Chena River was estimated by expansion of abundance estimates in four 3.2 km-long sample areas (Clark and Ridder 1987b, 1988), utilizing a stratified design (Cochran 1977). Expansion of these estimates was accomplished by first subdividing the Lower Chena River into two subsections. Each subsection was chosen on the basis of river morphology and hydrologic characteristics that might influence Arctic grayling density.

The first subsection (Lower Chena A) encompassed the lower 40 km of river (Figure 2). Lower Chena subsection A is characterized by straight, low gradient stretches of river interspersed with slow, deep pools. Gravel bars occur in the center of the channel and the river bank has been stabilized by man made structures (bridge abutments, riprap, and wooden pilings). The upper subsection of the Lower Chena (B) is 32 km long, extending from the crossing at Nordale Road to the Moose Creek Dam complex (Figure 2). Lower Chena subsection B is characterized by slow, meandering stretches interspersed with riffles.

Two of the four 3.2-km sample areas were randomly chosen in each of the subsections (2 strata, 2 samples per stratum; Figure 2). Multiple-sample population estimates were performed in each of the 3.2-km sample areas. Two of the areas were sampled once each day during a five day time span. Sampling took place between 10 and 20 July. Capture histories from each sample area were used as input to program CAPTURE (White et al. 1982). Program CAPTURE was used to perform a rigorous examination of assumptions necessary to multiple-sample abundance estimators. The assumptions necessary for accurate estimation of abundance in a closed population are (from Seber 1982):

- 1) the population is closed (no change in the number of Arctic grayling in the population during the estimation experiment);
- 2) all Arctic grayling have the same probability of capture in the first sample or in the second sample, or marked and unmarked Arctic grayling mix randomly between the first and second samples;
- 3) marking of Arctic grayling does not affect their probability of capture in the second sample;
- 4) Arctic grayling do not lose their mark between sampling events; and,
- 5) all marked Arctic grayling are reported when recovered in the second sample.

Assumption 1 could not be tested directly, but was implicitly assumed because of the short duration of the experiment (five days). Assumption 2 was tested

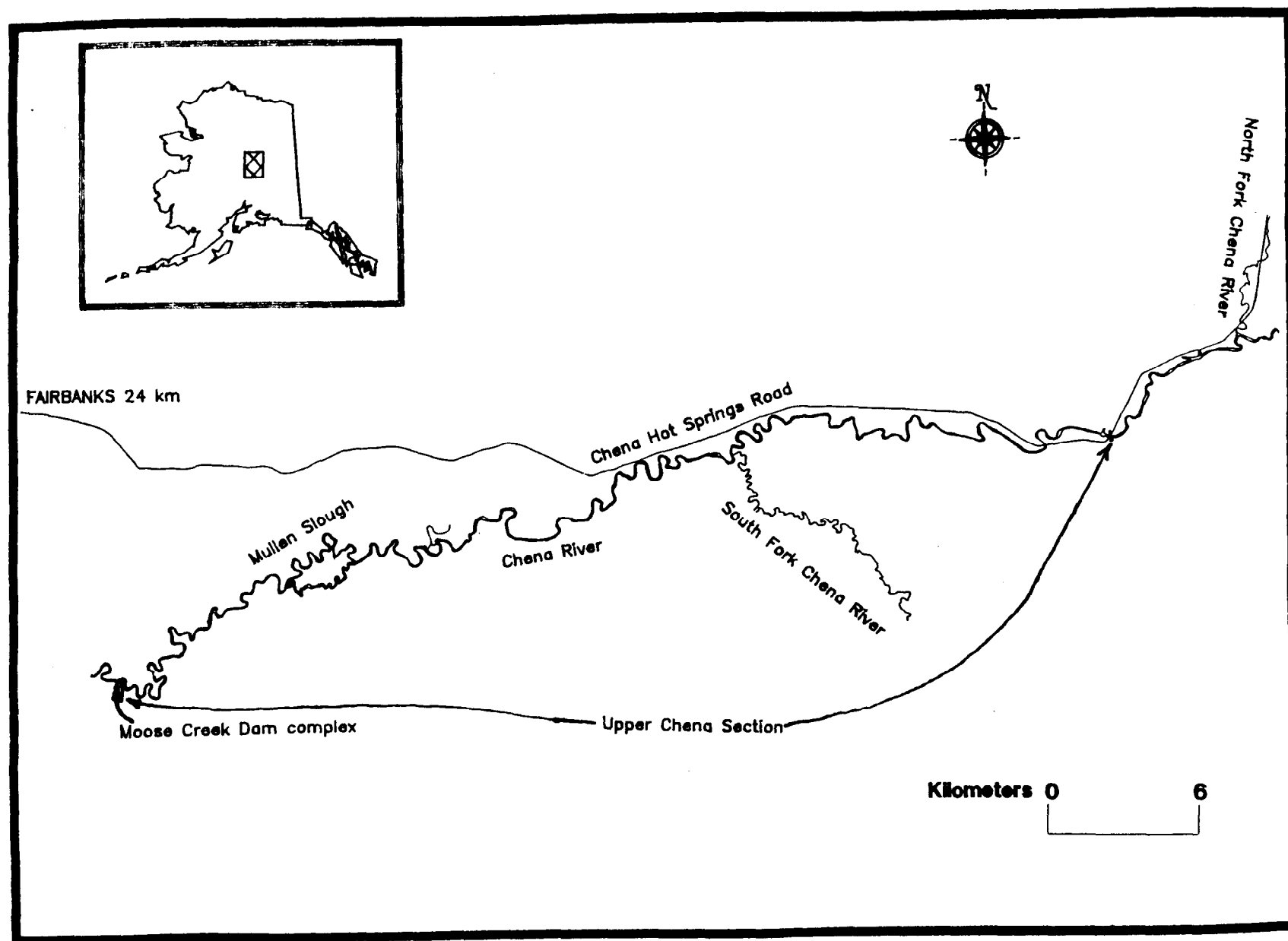


Figure 3. The Chena River above the Moose Creek Dam complex (Upper Chena River section).

with statistical procedures within program CAPTURE and with a Kolmogorov-Smirnov (Conover 1980) statistical test. Assumption 3 was tested for validity by program CAPTURE. Assumption 4 was assured of validity by double marking of Arctic grayling. Assumption 5 was assumed to be valid by rigorous examination of all Arctic grayling captured and by double marking.

Population abundance in the Lower Chena River was estimated by expanding the sample area estimates in each of the two subsections:

$$\hat{N}_i = R_i \hat{\bar{N}}_i \quad (1)$$

where: \hat{N}_i = the estimated abundance in stratum (subsection) i ;
 R_i = the possible number of sample areas in stratum i ;

$$\hat{\bar{N}}_i = \frac{\sum_{j=1}^{r_i} \hat{N}_{ij}}{r_i} = \text{average abundance in } r_i \text{ 3.2-km sample areas};$$

r_i = 2 3.2-km sample areas in stratum i ;

\hat{N}_{ij} = the abundance of Arctic grayling in sample area j of stratum i ;
 i = 1, 2 strata (Lower Chena A and Lower Chena B); and,
 j = 1, 2 sample areas (A1 and A2, B1 and B2).

Lower Chena A had 12.5 possible 3.2-km sample areas ($R_1 = 12.5$) and Lower Chena B had 10 possible 3.2-km sample areas ($R_2 = 10$). The variance of each subsection abundance estimate was (Cochran 1977):

$$V[\hat{N}_i] = R_i[R_i - r_i] S_i^2 + \frac{R_i^2}{r_i^2} \sum_{j=1}^{r_i} V[\hat{N}_{ij}] \quad (2)$$

where: $V[\hat{N}_i]$ = variance of estimated abundance in stratum i ;

$$S_i^2 = \frac{\sum_{j=1}^{r_i} (\hat{N}_{ij} - \hat{\bar{N}}_i)^2}{r_i(r_i - 1)};$$

$V[\hat{N}_{ij}]$ = variance of estimated abundance in sample area j of stratum i (from program CAPTURE); and,
 r_i = the number of 3.2-km sample areas sampled in stratum i .

Equations 1 and 2 were used to estimate abundance and variance in subsections Lower Chena A and Lower Chena B. Estimated abundance and variance of the Lower Chena section was calculated by summing the subsection (stratum) abundance estimates and summing the variances:

$$\hat{N}_L = \sum_{i=1}^2 \hat{N}_i ; \text{ and,} \quad (3)$$

$$V[\hat{N}_L] = \sum_{i=1}^2 V[\hat{N}_i] . \quad (4)$$

where: \hat{N}_L = estimate of Arctic grayling abundance in the Lower Chena River; and,
 $V[\hat{N}_L]$ = estimated variance of abundance of Arctic grayling in the Lower Chena River.

Upper Chena River:

Abundance of Arctic grayling greater than 149 mm FL was estimated with the modified Petersen estimator of Bailey (1951, 1952). Two electrofishing boats were used to mark Arctic grayling along both banks of the entire 80 km of the Upper Chena River. Marking of fish required four days, sampling four areas. After a hiatus of seven days the two electrofishing boats were used in the same way to examine Arctic grayling for marks. The entire experiment was conducted between 24 and 27 July for the first sample and between 31 July and 3 August for the second (recapture) sample.

Assumptions necessary for accurate estimation of abundance were identical to those listed in the Lower Chena River experiments. Assumption 1 was implicitly assumed because of the large size of the sample area (80 km) and short duration of the experiment (two weeks). Assumptions 2 and 3 were tested with two Kolmogorov-Smirnov statistical tests. The first test compared the length frequency distributions of recaptured Arctic grayling with those captured during the marking run. The second test compared the length frequency distributions of Arctic grayling captured during the marking run with those captured in the recapture run. In addition, sampling was conducted with equal effort along the entire 80 km of river, so it was assumed that all Arctic grayling had equal probability of capture throughout the Upper Chena River section. The assumption of equal probability of capture along the entire 80 km of river was tested with a chi-squared contingency table. The recapture to mark ratios were compared for the four areas of the Upper Chena. Assumptions 4 and 5 were assumed to be valid because of double marking of tagged Arctic grayling and rigorous examination of all captured Arctic grayling.

Estimated abundance was calculated from numbers of Arctic grayling marked, examined for marks, and recaptured (Bailey 1951; Seber 1982):

$$\hat{N}_U = \frac{M (C + 1)}{(R + 1)} - 1 \quad (5)$$

where: M = the number of Arctic grayling marked and released alive during the first sample;

C = the number of Arctic grayling examined for marks during the second sample;
 R = the number of Arctic grayling recaptured during the second sample; and,
 N_U = estimated abundance of Arctic grayling during the first sample.

Bailey's (1951, 1952) modification was used instead of the more familiar modification by Chapman (1951) because of the sampling design used on the Upper Chena River section. Seber (1982) found that if the assumption of a random sample for the second sample was false and a systematic sample was taken (for example, a systematic sample of both banks of the Chena River), then the binomial model of Bailey (1951, 1952) is most appropriate. The binomial model will hold in this situation when:

- 1) there is uniform mixing of marked and unmarked fish; and,
- 2) all fish, whether marked or unmarked, have the same probability of capture.

The Upper Chena River section sample design does not allow for thorough mixing of fish marked at the uppermost reaches with those marked in the downstream reaches, although local mixing of marked and unmarked fish probably occurs.

Variance of the estimate ($V[N_U]$) was calculated by bootstrapping the capture histories of all fish in both samples 1,000 times (Efron 1982). The bootstrap procedure also permitted examination of bias in the Petersen estimate by generating a bootstrap estimate in addition to a bootstrap variance. The bootstrap procedure is as follows:

- 1) generate a pseudorandom number (between 0 and 1);
- 2) sample capture history of fish number "random number" \times "total number of fish" + 1;
- 3) repeat 1 and 2 until a sample of "total number of fish" is taken;
- 4) generate population estimate from randomly sampled capture histories using equation 5;
- 5) repeat 1 through 4 for 1,000 iterations; and,
- 6) calculate mean and variance of 1,000 iterations of population estimate.

Estimated abundance and variance in the entire Chena River was calculated as the sum of Lower Chena and Upper Chena River estimates:

$$\hat{N} = \hat{N}_L + \hat{N}_U ; \text{ and,} \quad (6)$$

$$V[\hat{N}] = V[\hat{N}_L] + V[\hat{N}_U]. \quad (7)$$

Age and Size Composition

Collections of Arctic grayling for age-length samples were conducted in conjunction with abundance estimation experiments. The Lower Chena River age-length samples were analyzed independently of the Upper Chena River age-length samples.

Lower Chena River:

A stratified design was used to derive age composition estimates for the Lower Chena River. This design was identical to the estimator for population abundance except that equations 1 through 4 were further partitioned into age classes. Therefore, abundance of age k Arctic grayling in the Lower Chena was estimated by equations 1 through 4. Using the estimates of abundance for age k ($k = 1, 2, 3, \dots, o$ age classes) and the abundance estimates (N_i 's), age composition of the Lower Chena River was estimated. First the proportions for each age class were estimated in each of the two sample areas for each of the two subsections of the Lower Chena:

$$\hat{p}_{ijk} = \frac{y_{ijk}}{n_{ij}} \quad (8)$$

where: y_{ijk} = the number of age k Arctic grayling sampled in sample area j of subsection (stratum) i ; and,
 n_{ij} = the number of Arctic grayling sampled in sample area j of subsection i .

Variance of these proportions was estimated by:

$$V[\hat{p}_{ijk}] = \frac{\hat{p}_{ijk} (1 - \hat{p}_{ijk})}{n_{ij} - 1} \quad (9)$$

The sample area abundance estimates were used to weight each of the proportions from the respective sample area:

$$\hat{N}_{ijk} = \hat{N}_{ij} \hat{p}_{ijk} \quad (10)$$

where: \hat{N}_{ijk} = the estimated abundance of age k Arctic grayling in sample area j of stratum i .

Variance of this product was approximated by Goodman (1960):

$$V[\hat{N}_{ijk}] = \hat{p}_{ijk} V[\hat{N}_{ij}] + \hat{N}_{ij} V[\hat{p}_{ijk}] - V[\hat{p}_{ijk}] V[\hat{N}_{ij}] \quad (11)$$

By substituting N_{ijk} and $V[N_{ijk}]$ for N_{ij} and $V[N_{ij}]$ in equations 1 through 4, the resulting abundance estimates by age class (N_{Lk} 's) were used to estimate age composition for the Lower Chena River.

Proportion of the population by age class was calculated as:

$$\hat{p}_{Lk} = \frac{\hat{N}_{Lk}}{\hat{N}_L} \quad (12)$$

where: \hat{p}_{Lk} = the proportion of age k Arctic grayling in the Lower Chena River;
 \hat{N}_{Lk} = the abundance of age k Arctic grayling in the Lower Chena River (from substitution into equations 1 through 4); and,
 \hat{N}_L = the abundance of Arctic grayling in the Lower Chena River.

Bernard (1983) approximated the variance of the quotient of two dependent variables as (ignoring hat symbols):

$$V[p_{Lk}] = \left[\frac{N_{Lk}}{N_L} \right]^2 \left[\frac{V[N_{Lk}]}{N_{Lk}^2} + \frac{V[N_L]}{N_L^2} - \frac{2V[N_{Lk}]}{N_L N_{Lk}} \right] \quad (13)$$

Size composition of Arctic grayling in the Lower Chena River was characterized by the Relative Stock Density (RSD) indices of Gabelhouse (1984). The RSD categories for Arctic grayling are: "stock" (150 to 269 mm FL); "quality" (270 to 339 mm FL); "preferred" (340 to 449 mm FL); "memorable" (450 to 559 mm FL); and "trophy" (greater than 559 mm FL). Estimation of RSD for the Chena River follows that of age composition estimates (equations 1 through 4 and 8 through 13). RSD estimates and variances were calculated by substituting "age class k " with "RSD category k ."

Upper Chena River:

Age composition of Upper Chena River Arctic grayling could have been calculated directly from age-length samples taken during the first sample of the mark-recapture estimate. However, a statistical difference in the capture probabilities by lengths of fish was detected (from tests of assumptions 2 and 3). Using the estimates of capture probability by size class, adjustment factors were estimated and used to correct for the bias. First, the capture probabilities were estimated from the recapture to mark ratios in each of two size classes:

$$\hat{\rho}_1 = \frac{\hat{RECAP}_1}{\hat{MARK}_1} \quad (14)$$

where: $\hat{\rho}_1$ = the capture probability of Arctic grayling in size class 1, regardless of age k ;
 \hat{RECAP}_1 = the number of recaptures of Arctic grayling in size class 1;
 and,
 \hat{MARK}_1 = the number of marked Arctic grayling in size class 1.

The two size classes were 150 through 259 mm FL and greater than 259 mm FL. These categories were chosen by examining plots of the cumulative distribution functions of fork length for fish marked and fish recaptured during the abundance estimation experiment.

From the ratio of the largest capture probability to the capture probability in size class 1, an adjustment to the number sampled at age k that are also of size class 1 was estimated (ignoring the hat symbols of ρ):

$$\hat{A}_1 = \frac{\hat{\rho}_L}{\hat{\rho}_1} \quad (15)$$

where: \hat{A}_1 = the adjustment factor for all Arctic grayling of size class 1, regardless of age class k ; and,
 $\hat{\rho}_L = \max(\hat{\rho}_1)$, $l = 1, 2$ size classes (represented by m).

The adjustment factor was multiplied by the number of Arctic grayling sampled at age k that were also in size class 1:

$$\hat{x}_{k1} = \hat{A}_1 n_{k1} \quad (16)$$

where: \hat{x}_{k1} = the adjusted number of Arctic grayling of age k that were also in size class 1; and,
 n_{k1} = the actual number of Arctic grayling sampled that were age k and also in size class 1.

The proportion of Arctic grayling that were age k then reevaluates to:

$$\hat{p}_k = \frac{\sum_{l=1}^m \hat{x}_{kl}}{\sum_{k=1}^o \sum_{l=1}^m \hat{x}_{kl}} = \frac{\hat{x}_k}{\hat{x}_{..}} \quad (17)$$

where: $k = 1, 2, \dots, o$ age classes; and,
 $l = 1, 2$ size classes (represented by m).

The variances of these adjusted proportions were estimated by bootstrap techniques (Efron 1982). The adjustment factors (recapture to mark ratios) from bootstrapping of capture histories were used to estimate variance of the proportions. Using equations 10 and 11 to apportion the abundance estimate by age class, the resulting abundance estimates at age k (N_{Uk} 's) and variances ($V[N_{Uk}]$'s) were then added to the corresponding N_{Lk} and $V[N_{Lk}]$ to estimate abundance at age in the entire Chena River. Age composition and variance in the entire Chena River was then estimated by equations 12 and 13.

Size composition of Arctic grayling in the Upper Chena River was described by the RSD categories as described above. The same adjustment factors (equation 14) were used to adjust biased RSD estimates, replacing the number sampled at age k that were also in size class 1 (n_{k1}) with the number sampled in RSD category k ($k = 1, 2, 3, 4$, and 5 RSD categories) that were also in size class 1. The adjusted RSD estimates, expanded to abundance by RSD category, were then added to abundance by RSD category from the Lower Chena River. RSD proportions and variances for the entire Chena River were then estimated with equations 12 and 13.

Survival and Recruitment

As of 1989, four years of population abundance and age composition estimates had been completed for the lower 152 km of the Chena River. Using data from 1986 through 1988, Clark (1989) reported on survival rates and recruitment for 1986 and 1987. Survival rate and recruitment for 1988 were calculated in the same manner.

Annual recruitment was defined as the number of age 3 Arctic grayling added to the population between year t and year $t+1$, and alive in year $t+1$. Estimates of recruitment were calculated with population abundance estimates and estimates of the proportion of age 3 Arctic grayling in 1988 and 1989:

$$\hat{A}_{t,t+1} = \hat{N}_{t+1} \hat{p}_{3,t+1} \quad (18)$$

where: $\hat{A}_{t,t+1}$ = recruits entering the population between year t and year $t+1$, and alive in year $t+1$;
 \hat{N}_{t+1} = number of fish age 3 and older in the population in year $t+1$; and,
 $\hat{p}_{3,t+1}$ = the proportion of age 3 Arctic grayling in the population in year $t+1$.

Variance of annual recruitment was estimated with equation 11, the variance of a product. With recruitment and population abundance estimates in years t and $t+1$, the estimate of survival rate between year t and year $t+1$ becomes:

$$\hat{S}_{t,t+1} = \frac{\hat{N}_{t+1} - \hat{A}_{t,t+1}}{\hat{N}_t} \quad (19)$$

The variance of annual survival was approximated as the variance of a quotient of two independent variables with the delta method (Seber 1982; ignoring hat symbols):

$$V[S] = \left[\frac{N'_{t+1}}{N_t} \right]^2 \left[\frac{V[N'_{t+1}]}{N'^2_{t+1}} + \frac{V[N_t]}{N_t^2} \right] \quad (20)$$

where: $N'_{t+1} = N_{t+1} - A_{t,t+1}$; and,

$$V[N'_{t+1}] = V[N_{t+1}] + V[A_{t,t+1}].$$

Historic Data Summaries

Data collected from the Chena River (1955 to 1989) were summarized in Appendix A. Creel census estimates, population abundance estimates, length at age estimates, age composition estimates, size composition estimates, and a model of Arctic grayling growth were summarized from Federal Aid in Sport Fish Restoration reports and State of Alaska Fishery Data Series reports written from 1959 to the present (Appendix A). When possible, estimates of precision were reported with point estimates. Precision was reported as either standard error or 95% confidence interval. Sample sizes were reported if neither of these estimates of precision were available. Length frequency was generally reported in the literature as numbers sampled per 10 mm length increment. The length frequency distributions were converted into the RSD categories of Gabelhouse (1984) for comparison with data collected from 1986 to 1989. In addition to the aforementioned reports in Appendix A, Arctic grayling migration studies were summarized in a report by Tack (1980). Reports concerning Arctic grayling research from 1952-1980 were compiled by Armstrong (1982). Armstrong et al. (1986) have compiled a bibliography for the genus *Thymallus* to 1985.

RESULTS

Lower Chena River

A total of 671 Arctic grayling (≥ 150 mm FL) was captured during mark-recapture experiments in the Lower Chena River. Four immediate mortalities or serious injuries were recorded for an overall injury rate of 0.6%.

No significant changes in capture probabilities by length of fish occurred in the sample areas during population estimation (Kolmogorov-Smirnov test statistics and tail probabilities for each sample area are: A1(DN = 0.19, $P = 0.34$); A2(DN = 0.18, $P = 1.00$); B1(DN = 0.088, $P = 1.00$); B2(DN = 0.14, $P = 1.00$; Figure 4). However, program CAPTURE detected significant changes in behavior of marked Arctic grayling as the experiments progressed (Table 2). In three sample areas, variability in capture probability was attributed to behavioral responses to first capture (see White et al. 1982).

In sample area B2, CAPTURE found both temporal and behavioral components to change in capture probability during the experiment. Looking at the Kolmogorov-Smirnov plots of cumulative distributions (CDF; Figure 4), a change in capture probability was evident at approximately 260 mm FL. Although the two distributions were not significantly different, complete stratification of the experiment at 260 mm FL resulted in two separate populations for which CAPTURE could provide valid estimators. The estimate for small Arctic grayling contained a significant behavioral component to changing capture probabilities (estimated abundance = 47). The estimate for large Arctic grayling showed no change in capture probabilities (estimated

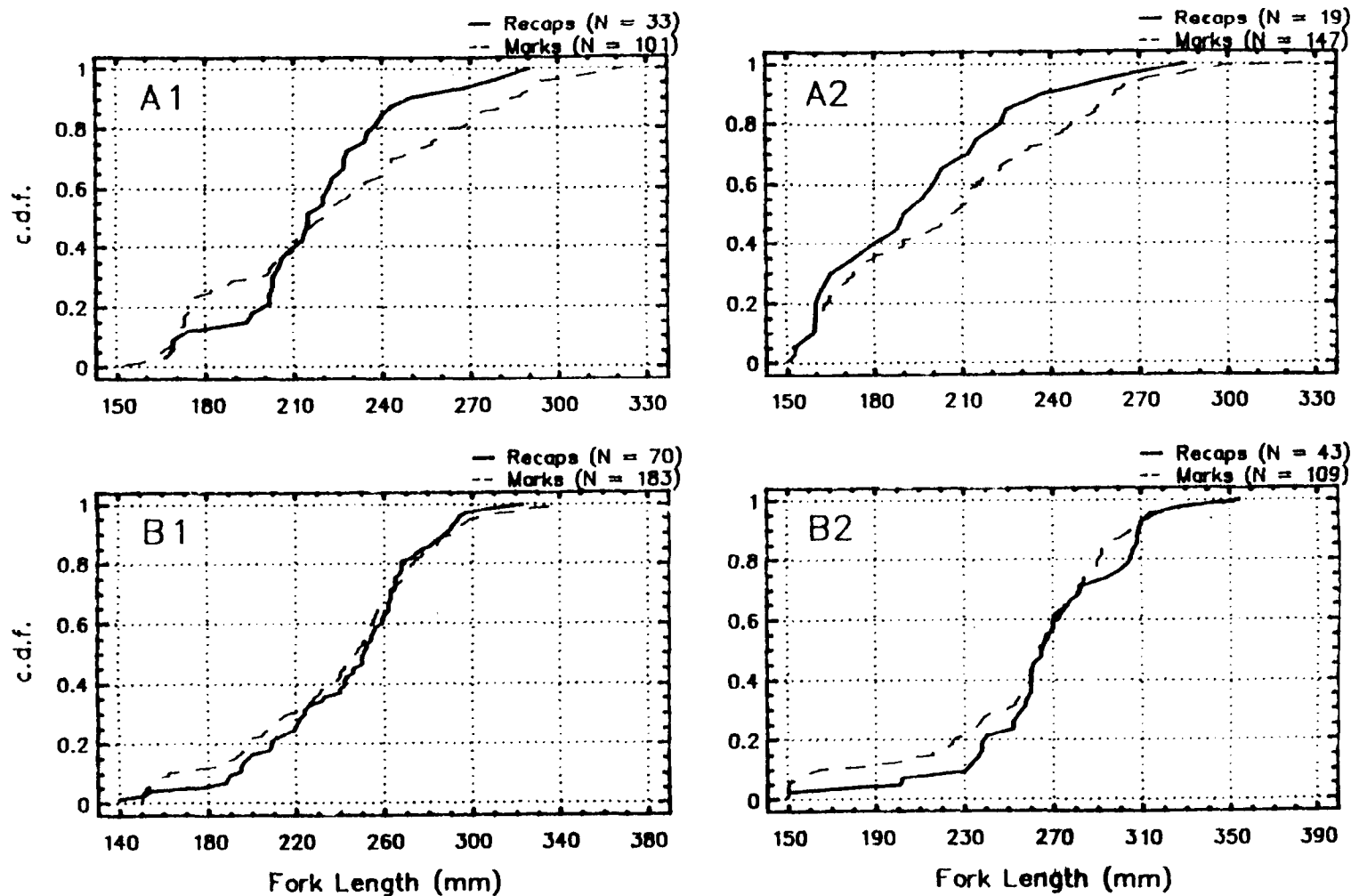


Figure 4. Cumulative distribution functions (c.d.f) of lengths of Arctic grayling marked versus lengths of Arctic grayling recaptured for four 3.2-km sample areas of the Lower Chena section of the Chena River, 10 through 20 July, 1989.

Table 2. Summary of sample area abundance estimates of Arctic grayling (≥ 150 mm FL) in the Lower Chena section of the Chena River, 10 through 20 July, 1989.

Subsection	River KM	CAPTURE Model ^a	Abundance Estimate	Standard Error	Fish/km
A1	11.2 to 14.4	M _b	167	30	52
A2	19.2 to 22.4	M _b	225	35	70
B1	41.6 to 44.8	M _b	195	19	61
B2	56.0 to 59.2	M _b , M _o ^b	148	14	46

^a Models selected by program CAPTURE as most appropriate:

M_b: behavioral changes in probability of capture; and,

M_o: constant probability of capture.

These models and their estimators are described in White et al. (1982) and Otis et al. (1978).

^b Model M_b was chosen for fish greater than 149 mm FL and less than 261 mm FL. Model M_o was chosen for fish greater than 260 mm FL.

abundance = 101). Estimated abundance in sample area B2 was 148 Arctic grayling (SE = 14 Arctic grayling, $CV^2 = 9.5\%$; Table 2).

In sample areas A1, A2, and B1 program CAPTURE estimated population abundance without stratification by length. In all three sample areas a significant behavioral component caused a change in capture probability. Model M_h (Otis et al. 1978) was chosen as most appropriate for all three sample area abundance estimates. Estimated abundance in sample area A1 was 167 Arctic grayling (SE = 30 Arctic grayling, $CV = 18.0\%$; Table 2). Estimated abundance in sample area A2 was 225 Arctic grayling (SE = 35 Arctic grayling, $CV = 15.5\%$; Table 2). Estimated abundance in sample area B1 was 195 Arctic grayling (SE = 19 Arctic grayling, $CV = 9.7\%$; Table 2).

Expansion of estimated abundance in sample areas A1 and A2 resulted in an estimated population size of 2,450 Arctic grayling in subsection A of the Lower Chena River (Table 3). Expansion of estimates in sample areas B1 and B2 to all of subsection B resulted in an estimate of 1,715 Arctic grayling (Table 3). Estimated abundance of Arctic grayling in the Lower Chena River was 4,165 fish (SE = 501 fish, $CV = 12.0\%$).

Age composition of samples taken from sample areas A1 and A2 of subsection A of the Lower Chena River were not significantly different ($\chi^2 = 6.98$, $df = 4$, $0.10 < P < 0.25$; Figure 5; Table 4). However, a significant difference was found in samples taken from sample areas B1 and B2 of subsection B ($\chi^2 = 11.83$, $df = 5$, $P < 0.05$; Figure 5; Table 4). Therefore, age composition data were expanded by sample area to adjust for differences in age composition within subsection B. Age 3 Arctic grayling dominated the estimated age composition of the Lower Chena River in 1989. Of the estimated 4,165 Arctic grayling in the Lower Chena River, 1,059 fish (SE = 191 fish, $CV = 18.0\%$), or 25.4% were age 3 (Table 4). The abundance estimate for age 2 fish was most likely biased because of the imposed lower length limit for mark-recapture experiments (150 mm FL). However, age 2 Arctic grayling made up 23.3% of the estimated abundance in the Lower Chena. Age 6 Arctic grayling were next most abundant, representing 19.8% of the stock, or 823 fish (SE = 87 fish, $CV = 10.6\%$). Very few Arctic grayling older than age 6 were found in the Lower Chena River (Table 4).

Size composition samples taken from subsection A were significantly different ($\chi^2 = 8.73$, $df = 1$, $P < 0.01$; Figure 6; Table 5). Size composition estimates in the two sample areas in subsection B were also significantly different ($\chi^2 = 19.67$, $df = 1$, $P < 0.01$; Figure 6; Table 5). Therefore, size composition data were expanded by sample area to adjust for differences in size composition within the subsections. Eighty percent of Arctic grayling greater than 149 mm FL were also less than 270 mm FL (Table 5). Of the 821 Arctic grayling (SE = 151 fish, $CV = 18.4\%$) greater than 270 mm FL, only 5 fish (SE = 7 fish, $CV = 140.0\%$) were of preferred size (≥ 340 mm FL). No memorable or trophy size Arctic grayling were sampled from the Lower Chena River.

² $CV =$ standard error (SE) divided by the point estimate expressed as a percentage.

Table 3. Estimated abundance of Arctic grayling (≥ 150 mm FL) in the lower 72 kilometers of the Chena River (Lower Chena section), 10 through 21 July, 1989.

Subsection ^a	Subsection Length (km)	Estimated Abundance	Variance	Standard Error
A1	3.2	167	916	30
A2	3.2	225	1,204	35
Average	3.2	196	841	29
Total	40.0	2,450	193,192	440
B1	3.2	195	358	19
B2	3.2	148	193	14
Average	3.2	172	552	24
Total	32.0	1,715	57,957	241
Lower Chena	72.0	4,165	251,149	501

^a Subsection A1 = river km 11.2 to 14.4; A2 = river km 19.2 to 22.4;
B1 = river km 41.6 to 44.8; and, B2 = river km 56.0 to 59.2.

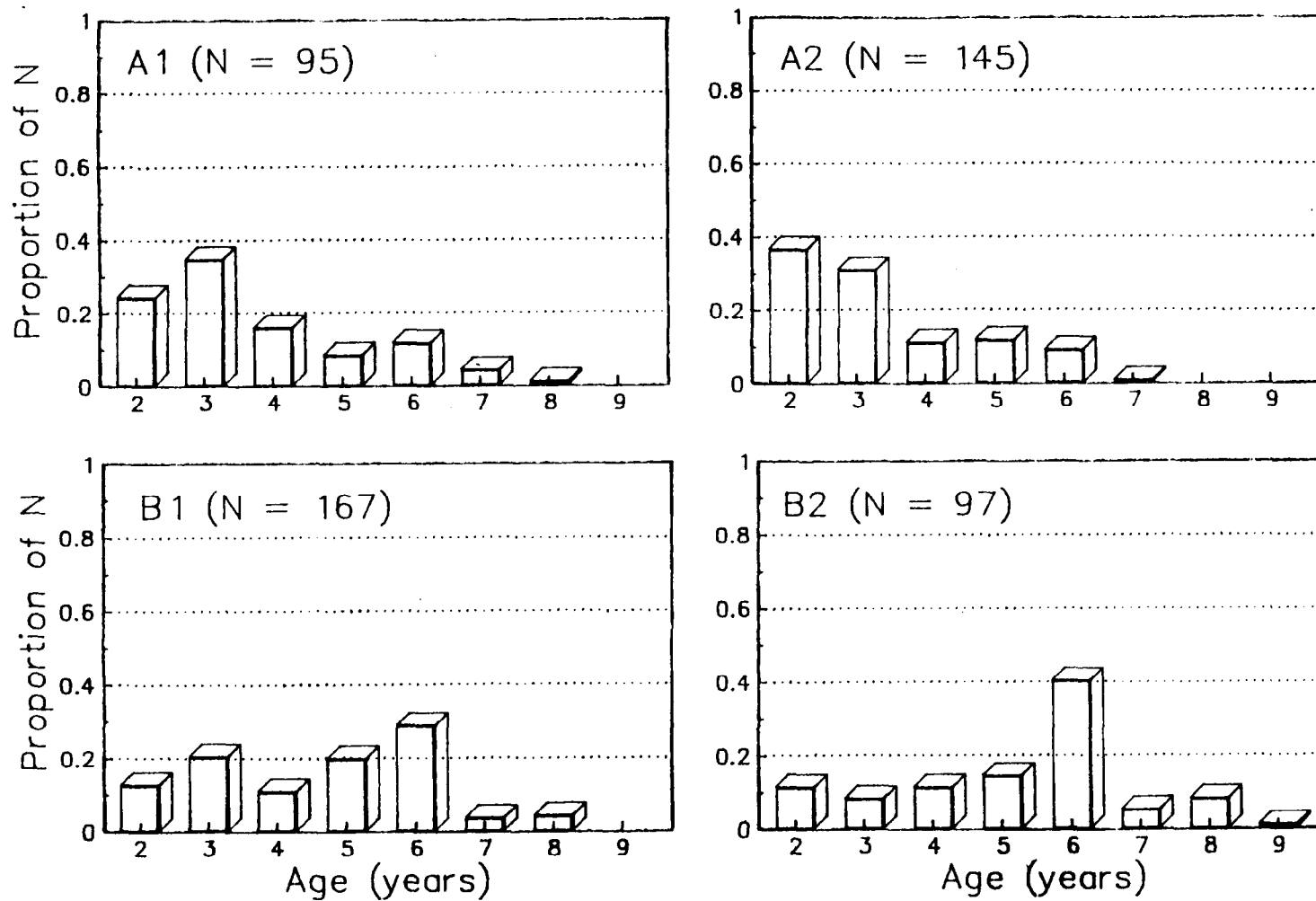


Figure 5. Age compositions of Arctic grayling sampled from each of four 32.2-km sample areas of the Lower Chena section of the Chena River, 10 July through 20 July, 1989 (N = sample size).

Table 4. Estimates of age composition and abundance by age with standard errors from Arctic grayling (≥ 150 mm FL) captured by pulsed-DC electrofishing in the Lower Chena section of the Chena River, 10 to 20 July, 1989.

Age	Subsection A1 ^a					Subsection A2 ^b					Subsection B1 ^c					Subsection B2 ^d					Lower Chena ^e			
	n ^f	p ^g	SE ^h	N ⁱ	SE ^j	n	p	SE	N	SE	n	p	SE	N	SE	n	p	SE	N	SE	p	SE	N	SE
2	23	0.24	0.04	40	10	53	0.37	0.04	82	16	21	0.13	0.03	25	6	11	0.11	0.03	17	5	0.23	0.06	972	272
3	33	0.35	0.05	58	13	45	0.31	0.04	70	14	34	0.20	0.03	40	7	8	0.08	0.03	12	4	0.25	0.04	1,059	191
4	15	0.16	0.04	26	8	16	0.11	0.03	25	7	18	0.11	0.02	21	5	11	0.11	0.03	17	5	0.12	0.02	508	77
5	8	0.08	0.03	14	5	17	0.12	0.03	26	7	33	0.20	0.03	39	7	14	0.14	0.04	21	6	0.13	0.03	549	128
6	11	0.12	0.03	19	6	13	0.09	0.02	20	6	48	0.29	0.04	56	9	39	0.40	0.06	60	9	0.20	0.03	823	87
7	4	0.04	0.02	7	4	1	0.01	0.01	2	2	6	0.04	0.01	7	3	5	0.05	0.02	8	3	0.03	0.01	131	44
8	1	0.01	0.01	2	2	0	0.00	0.00	0	0	7	0.04	0.02	8	3	8	0.08	0.03	12	4	0.03	0.01	113	36
9	0	0.00	0.00	0	0	0	0.00	0.00	0	0	0	0.00	0.01	0	0	1	0.01	0.01	2	2	<0.01	<0.01	10	11
Total	95	1.00	---	167	30	145	1.00	---	225	35	167	1.00	---	195	19	97	1.00	---	148	14	1.00	---	4,165	501

^a Subsection A1 - River kilometer 11.2 to 14.4; 10 July to 14 July.

^b Subsection A2 - River kilometer 19.2 to 22.4; 10 July to 14 July.

^c Subsection B1 - River kilometer 41.6 to 44.8; 17 July to 21 July.

^d Subsection B2 - River kilometer 56.0 to 59.2; 17 July to 21 July.

^e Expansion to the entire Lower Chena section - River kilometer 0 to 72.0.

^f n = number of Arctic grayling sampled at age.

^g p = estimated proportion of Arctic grayling at age in the subsection.

^h SE = estimated standard error of p (normal approximation to binomial).

ⁱ N = estimated subsection abundance of Arctic grayling at age.

^j SE = estimated standard error of N.

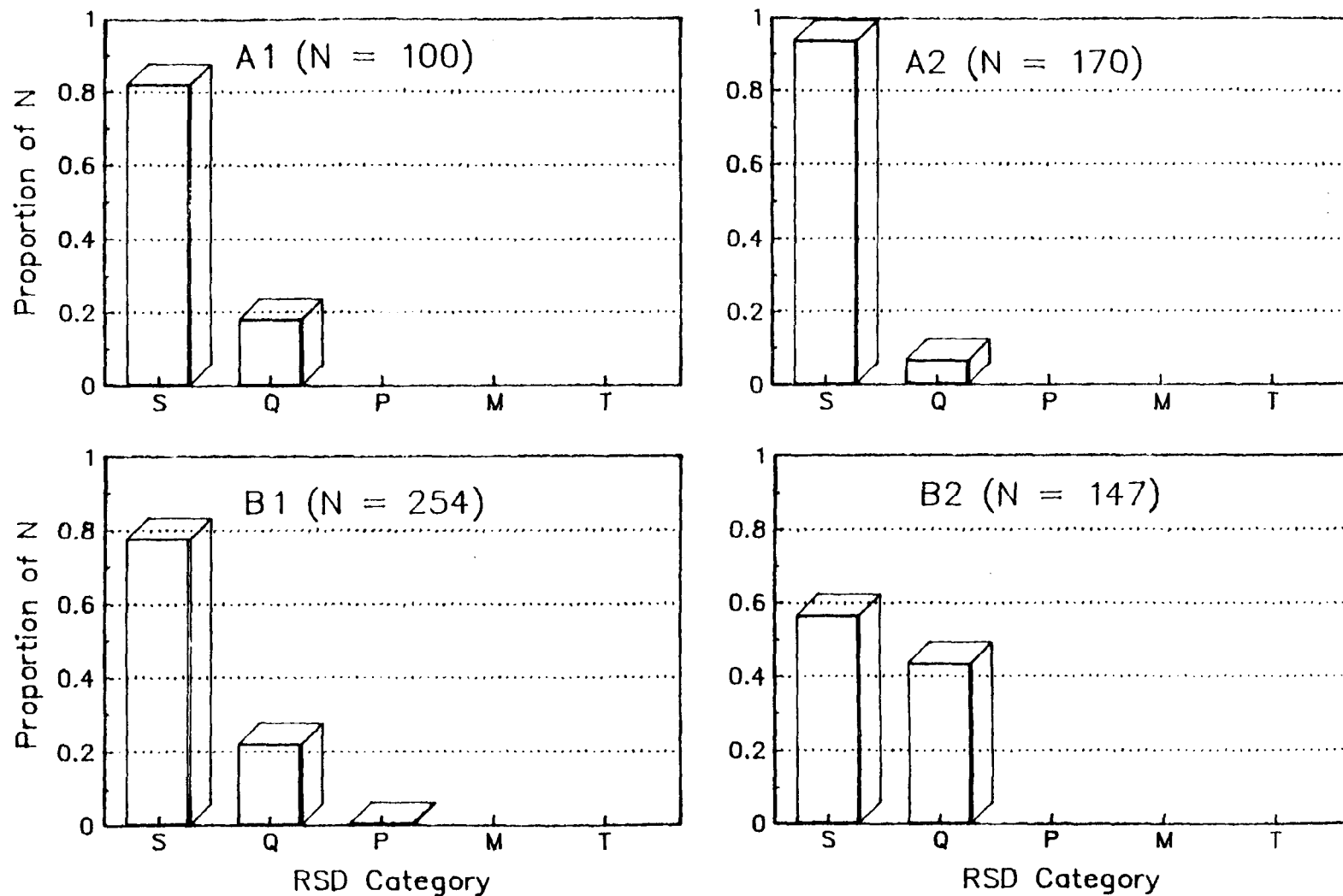


Figure 6. Size compositions of Arctic grayling sampled from each of four 3.2-km sample areas of the Lower Chena section of the Chena River, 10 July through 20 July, 1989 (N = sample size; S = stock (150 to 269 mm FL), Q = quality (270 to 339 mm FL), P = preferred (340 to 449 mm FL), M = memorable (450 to 559 mm FL), and T = trophy (greater than 559 mm FL).

Table 5. Summary of Relative Stock Density (RSD) indices of Arctic grayling (≥ 150 mm FL) captured in the Lower Chena section of the Chena River, 10 through 20 July, 1989.

	RSD Category ^a				
	Stock	Quality	Preferred	Memorable	Trophy
<u>Subsection A1^b</u>					
Number sampled	82	18	0	0	0
RSD	0.82	0.18	0.00	0.00	0.00
Standard Error	0.04	0.04	0.00	0.00	0.00
Abundance ^c	137	30	0	0	0
Standard Error	26	8	0	0	0
<u>Subsection A2</u>					
Number sampled	159	11	0	0	0
RSD	0.94	0.07	0.00	0.00	0.00
Standard Error	0.02	0.02	0.00	0.00	0.00
Abundance	210	15	0	0	0
Standard Error	33	5	0	0	0
<u>Subsection B1</u>					
Number sampled	197	56	1	0	0
RSD	0.78	0.22	<0.01	0.00	0.00
Standard Error	0.03	0.03	<0.01	0.00	0.00
Abundance	151	43	1	0	0
Standard Error	16	7	1	0	0
<u>Subsection B2</u>					
Number sampled	83	64	0	0	0
RSD	0.57	0.44	0.00	0.00	0.00
Standard Error	0.04	0.04	0.00	0.00	0.00
Abundance	84	64	0	0	0
Standard Error	10	9	0	0	0
<u>Lower Chena</u>					
RSD	0.80	0.20	<0.01	0.00	0.00
Standard Error	0.04	0.04	<0.01	0.00	0.00
Abundance ^d	3,344	816	5	0	0
Standard Error	584	151	7	0	0

^a Minimum lengths for RSD categories are (Gabelhouse 1984):

Stock - 150 mm FL; Quality - 270 mm FL; Preferred - 340 mm FL;

Memorable - 450 mm FL; and, Trophy - 560 mm FL.

^b Subsections are: A1 - River kilometer 11.2 to 14.4; A2 - River kilometer 19.2 to 22.4; B1 - River kilometer 41.6 to 44.8; and, B2 - River kilometer 56.0 to 59.2.

^c Abundance is the estimated abundance in a 3.2 km subsection.

^d Abundance is the expanded abundance estimate in the lower 72.0 km of the Chena River by RSD category.

Upper Chena River

A total of 2,208 Arctic grayling (≥ 150 mm FL) was captured during the mark-recapture experiment on the Upper Chena River. Twenty immediate mortalities or serious injuries were recorded for an overall injury rate of 0.9%.

During 24 through 27 July, 1,255 Arctic grayling (≥ 150 mm FL) were marked and released along 80 km of the Upper Chena River. During 31 July through 3 August, 952 Arctic grayling were examined for marks along the same 80 km section of river. A total of 84 Arctic grayling was recaptured during the second sample. There was no significant difference in capture probabilities among the four areas of the Upper Chena ($\chi^2 = 4.90$, $df = 3$, $0.10 < P < 0.25$). No significant difference was found between the CDF of lengths of marked Arctic grayling and the CDF of lengths of recaptured Arctic grayling ($DN^3 = 0.14$, $P = 0.09$). However, the CDF of recaptures was most different than the CDF of marks for fish smaller than 260 mm FL (Figure 7A). The discrepancy in capture probabilities was small, but stratification of the mark-recapture data was deemed necessary for accurate estimation of abundance. Therefore, the mark-recapture data were stratified into small (150 to 259 mm FL) and large (≥ 260 mm FL) segments for separate estimation. The bootstrap estimate of Arctic grayling abundance for small fish was 6,073 fish (SE = 1,172 fish, CV = 19.3%; Table 6). The estimate for large fish was 8,790 fish (SE = 867 fish, CV = 9.9%; Table 6). The combined estimate of Arctic grayling abundance in the Upper Chena was 14,863 fish (SE = 1,458 fish, CV = 9.8%).

The CDF of lengths of marked Arctic grayling was significantly different than the CDF of lengths of Arctic grayling examined for marks ($DN = 0.07$, $P = 0.01$), although no functional difference was evident (Figure 7B). It was therefore judged that age-length samples taken during the marking and recapture events could be used to estimate age and size compositions of Arctic grayling in the Upper Chena River. The difference in capture probabilities of Arctic grayling by size noted above prompted the use of adjustment factors to remove bias from the age-length samples. After adjustment, age 3 and age 6 Arctic grayling were dominant in the Upper Chena River, representing 22.0% and 22.9% of the abundance, respectively (Table 7). Age 4 and age 5 fish were next most abundant, accounting for 14.2% and 13.6% of the abundance, respectively.

Size composition in the Upper Chena consisted of 50.4% stock size Arctic grayling (Table 8). Quality size Arctic grayling accounted for 42.9% of Upper Chena Arctic grayling. Least abundant were preferred size Arctic grayling, representing 5.3% of fish greater than 149 mm FL. No memorable or trophy size Arctic grayling were sampled on the Upper Chena River.

Chena River

The summed estimate of Arctic grayling abundance in the lower 152 km of the Chena River was 19,028 fish (SE = 1,542 fish, CV = 8.1%). Of these fish, 22.8% were age 3, representing an abundance of 4,332 fish (Table 9). The next

³ DN = test statistic for the Kolmogorov-Smirnov test.

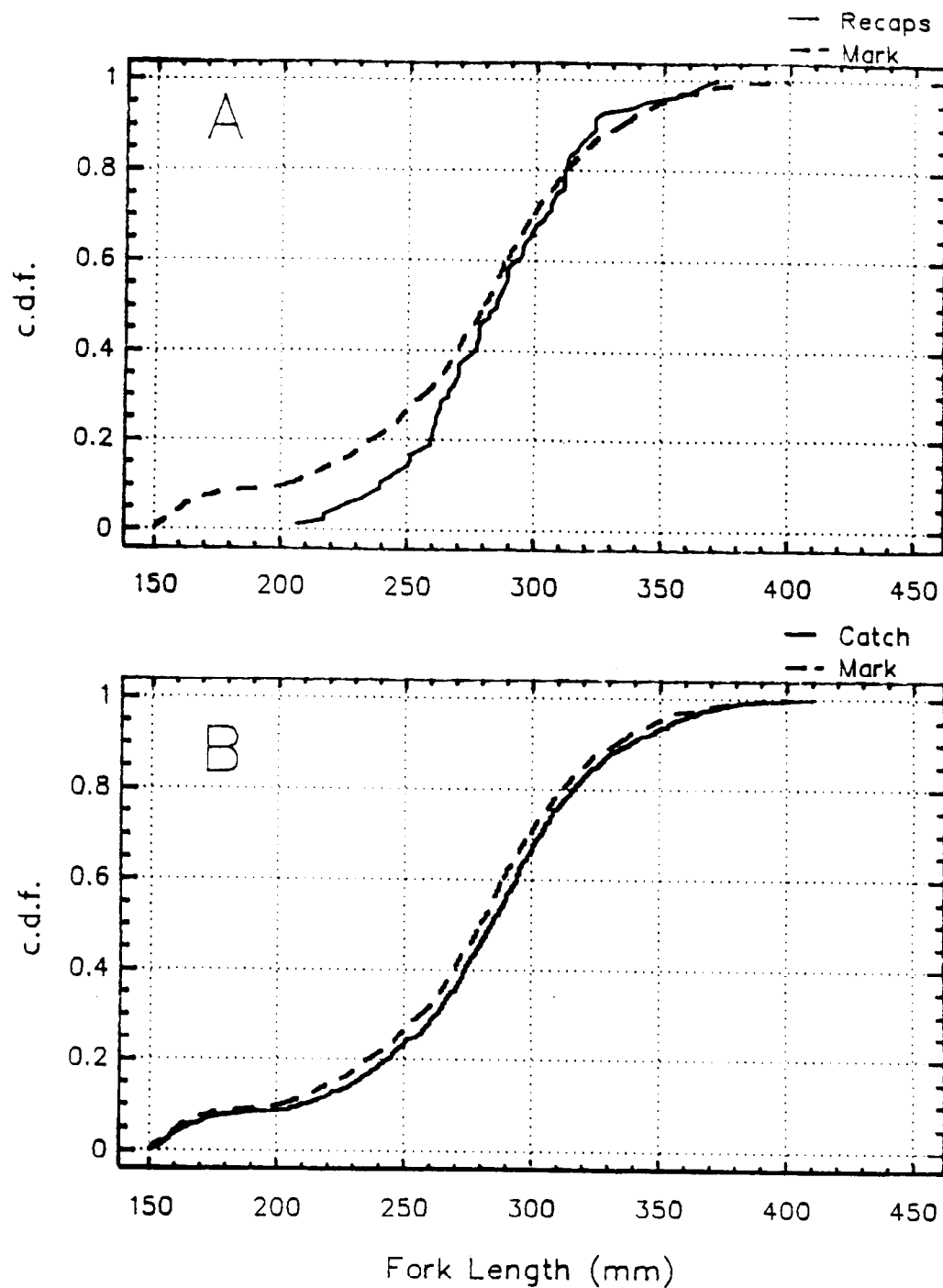


Figure 7. Cumulative distribution functions of lengths of Arctic grayling marked versus lengths of Arctic grayling recaptured (A) and versus lengths of Arctic grayling examined for marks (B) for the Upper Chena section of the Chena River, 24 July through 3 August, 1989.

Table 6. Capture probabilities and estimated abundance in two length categories used for population estimation of Arctic grayling (≥ 150 mm FL) in the Upper Chena section of the Chena River, 24 through 27 July, 1989.

Length Category	Mark n_1	Catch n_2	Recap m	ρ^a	$SE[\rho]^b$	N^c	$SE[N]^d$
150 to 259 mm	395	266	17	0.04	0.01	6,073	1,172
≥ 260 mm	860	686	67	0.08	0.01	8,790	867
Total	1,255	952	84	---	---	14,863	1,458

^a ρ is the probability of capture determined from bootstrap methods.

^b $SE[\rho]$ is the standard error of ρ determined from bootstrap methods.

^c N is the estimated abundance in a length category, determined from bootstrap methods.

^d $SE[N]$ is the bootstrap standard error of N .

Table 7. Estimates of adjusted age composition and abundance by age class with standard errors for Arctic grayling (≥ 150 mm FL) captured by pulsed-DC electrofishing from the Upper Chena section of the Chena River, 24 through 27 July, 1989.

Age	Age Composition				Abundance		
	n ^a	p ^b	SE ^c	CV ^d	N ^e	SE ^f	CV ^g
2	95	0.12	0.01	11.5	1,820	268	14.7
3	173	0.22	0.02	10.0	3,273	452	13.8
4	144	0.14	0.01	3.5	2,117	223	10.5
5	173	0.14	0.01	5.9	2,014	231	11.5
6	311	0.23	0.02	8.3	3,400	440	12.9
7	95	0.07	0.01	10.3	1,012	146	14.4
8	57	0.04	0.01	19.5	609	137	22.5
9	53	0.04	0.01	13.1	567	88	15.5
10	5	<0.01	<0.01	33.3	51	13	25.0
Total	1,106	1.000	---	---	14,863	1,458	9.8

^a n = number of Arctic grayling sampled at age.

^b p = estimated adjusted proportion of Arctic grayling at age in the population. Calculated with bootstrap methods (Efron 1982).

^c SE = estimated standard error of p. Calculated with bootstrap methods (Efron 1982).

^d CV = coefficient of variation of p, expressed as a percentage of p.

^e N = estimated population abundance of Arctic grayling at age.

^f SE = estimated standard error of N (Seber 1982).

^g CV = coefficient of variation of N, expressed as a percentage of N.

Table 8. Summary of Relative Stock Density (RSD) indices of Arctic grayling (≥ 150 mm FL) captured in the Lower and Upper Chena sections, and the Chena River, 1989.

	RSD Category ^a				
	Stock	Quality	Preferred	Memorable	Trophy
<u>Lower Chena</u>					
RSD	0.80	0.20	<0.01	0.00	0.00
Standard Error	0.04	0.04	<0.01	0.00	0.00
Abundance	3,344	816	5	0	0
Standard Error	584	151	7	0	0
<u>Upper Chena</u>					
Number sampled	842	1,191	183	0	0
RSD	0.38	0.54	0.08	0.00	0.00
Adjusted RSD ^b	0.50	0.43	0.07	0.00	0.00
Standard Error	0.03	0.03	0.01	0.00	0.00
Abundance	7,484	6,380	1,000	0	0
Standard Error	876	746	138	0	0
<u>Chena River</u>					
RSD	0.57	0.38	0.05	0.00	0.00
Standard Error	0.04	0.04	0.01	0.00	0.00
Abundance	10,828	7,196	1,005	0	0
Standard Error	1,053	761	138	0	0

^a Minimum lengths for RSD categories are (Gabelhouse 1984):

Stock - 150 mm FL; Quality - 270 mm FL; Preferred - 340 mm FL;

Memorable - 450 mm FL; and, Trophy - 560 mm FL.

^b Adjusted RSD is the RSD corrected for differential vulnerability by length from electrofishing. The adjustment is made with bootstrapping methods (Efron 1982). Standard error of RSD is for the adjusted estimate.

Table 9. Estimates of age composition and abundance by age with standard errors for Arctic grayling captured by pulsed-DC electrofishing from the Lower and Upper Chena sections and the Chena River, 1989.

Age	Lower Chena ^a				Upper Chena ^b				Chena River ^c			
	p ^d	SE ^e	N ^f	SE ^g	p	SE	N	SE	p	SE	N	SE
2	0.23	0.06	972	272	0.12	0.01	1,820	268	0.15	0.02	2,792	382
3	0.25	0.04	1,059	191	0.22	0.02	3,273	452	0.23	0.03	4,332	491
4	0.12	0.02	508	77	0.14	0.01	2,117	223	0.14	0.02	2,625	236
5	0.13	0.03	549	128	0.14	0.01	2,014	231	0.14	0.02	2,563	264
6	0.20	0.03	823	87	0.23	0.02	3,400	440	0.22	0.03	4,223	448
7	0.03	0.01	131	44	0.07	0.01	1,012	146	0.06	0.01	1,143	152
8	0.03	0.01	113	36	0.04	0.01	609	137	0.04	0.01	722	141
9	<0.01	<0.01	10	11	0.04	0.01	567	88	0.03	0.01	577	89
10	0.00	0.00	0	0	<0.01	<0.01	51	13	<0.01	<0.01	51	13
Totals	1.000	---	4,165	501	1.00	---	14,863	1,458	1.00	---	19,028	1,542

^a Lower Chena section - River kilometer 0 to 72.0.

^b Upper Chena section - River kilometer 72.0 to 152.0.

^c Chena River - River kilometer 0 to 152.0.

^d p = estimated proportion of Arctic grayling at age in the section.

^e SE = estimated standard error of p.

^f N = estimated population abundance of Arctic grayling at age in the section.

^g SE = estimated standard error of N.

most abundant age class was age 6, totalling 4,223 fish or 22.2%. Although not fully recruited to the mark-recapture estimates, age 2 Arctic grayling represented 14.7% of the estimated abundance or 2,792 fish (SE = 382 fish, CV = 13.7%). Of the 19,028 Arctic grayling greater than 149 mm FL, 56.9% or 10,828 fish (SE = 1,053, CV = 9.7%) were less than 270 mm FL (Table 8). Of the remaining 8,201 fish that were greater than 269 mm FL, 1,005 fish (SE = 138 fish, CV = 13.7%) were also greater than 339 mm FL. No memorable or trophy size Arctic grayling were captured in the lower 152 km of the Chena River.

Population size (age 3 and older) in summer of 1988 was 20,268 fish (SE = 1,214 fish, CV = 6.0%; Clark 1989). Annual recruitment from summer 1988 to summer 1989 was 4,332 fish (SE = 491 fish, CV = 11.3%; Table 10). Population size in summer of 1989 was 16,236 fish (SE = 1,618 fish, CV = 10.0%). Annual survival was estimated as 58.7% (SE = 9.0%, CV = 15.4%) between 1988 and 1989 (Table 10).

DISCUSSION

As in 1988 (Clark 1989), all stock status indicators were estimated with sufficient relative precision to permit estimation of annual recruitment and survival. During the past four years (1986 through 1989) population abundance, age and compositions, annual recruitment, and annual survival have been estimated on the lower 152 km of the Chena River (Clark and Ridder 1987b, 1988; Clark 1989). Estimates of recruitment and survival during this period indicate low, but increasing recruitment and increasing survival over time (Table 10; Figure 8). However, the last three estimates of recruitment are well below the long term average of approximately 13,000 recruits annually (Holmes et al. 1986). Additionally, if the present regulatory structure is kept in place, annual survival is not likely to increase beyond the level estimated for 1988 to 1989. Since population abundance has decreased during the last four years, levels of recruitment during these years have been insufficient to offset both fishing and natural mortality.

If survival rate has reached a maximum for the Arctic grayling stock under the present regulatory structure, then recruitment must increase for the population to rebuild. However, recruitment is not only a result of spawner abundance, but also depends upon environmental conditions immediately after spawning. Holmes (1984) and Holmes et al. (1986) found that high river discharge during June of the natal year negatively affected recruitment of Arctic grayling (numbers of age 3 fish) to the Chena River stock three years later. Under these conditions it is extremely difficult to estimate a level of recreational harvest that can be sustained over time. Experience has shown that an average annual harvest of 17,321 Arctic grayling (Table 1) is not sustainable.

However, if the principal dynamic rates can be estimated with sufficient precision, then models of the Chena River Arctic grayling stock can be created to simulate the population under various regulatory structures. Annual survival rates can be used to estimate instantaneous rates of mortality. Furthermore, annual patterns of exploitation must be superimposed upon the assumed annual pattern of natural mortality for unbiased estimation of

Table 10. Summary of population abundance, annual survival (%), annual recruitment, and standard error estimates during 1986-1989, and forecasts of recruitment during 1990 and 1991 for Arctic grayling (\geq age 3) in the lower 152 km of the Chena River.

Year	Abundance	SE	Survival	SE	Recruitment	SE
1986 ^a	61,581	26,987				
			43.9	20.1	2,526	358
1987 ^a	29,580	3,525				
			57.1	8.1	3,373	529
1988 ^a	20,268	1,214				
			58.7	9.0	4,332	491
1989	16,236	1,618				
					12,500	---
1990 ^b						
					6,500	---
1991 ^b						

^a Source document for parameter estimates in these years is Clark (1989).

^b Recruitment estimates for 1989-1990 and 1990-1991 are forecast with an environment-dependent stock-recruitment model developed for the Chena River (Clark Unpublished).

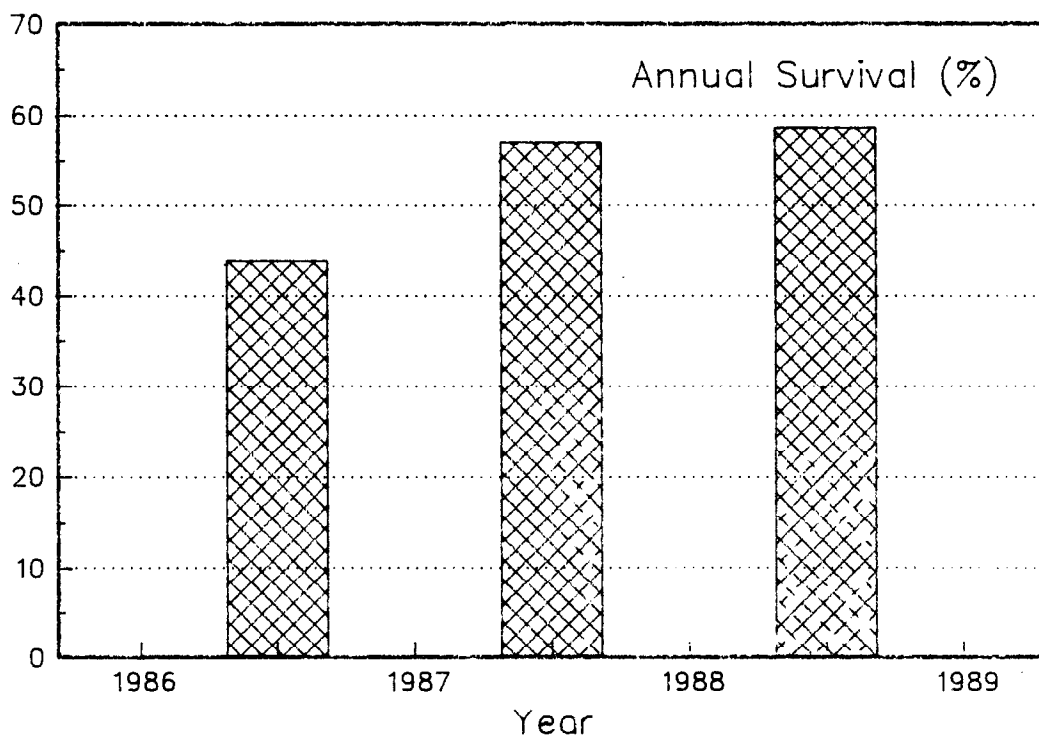
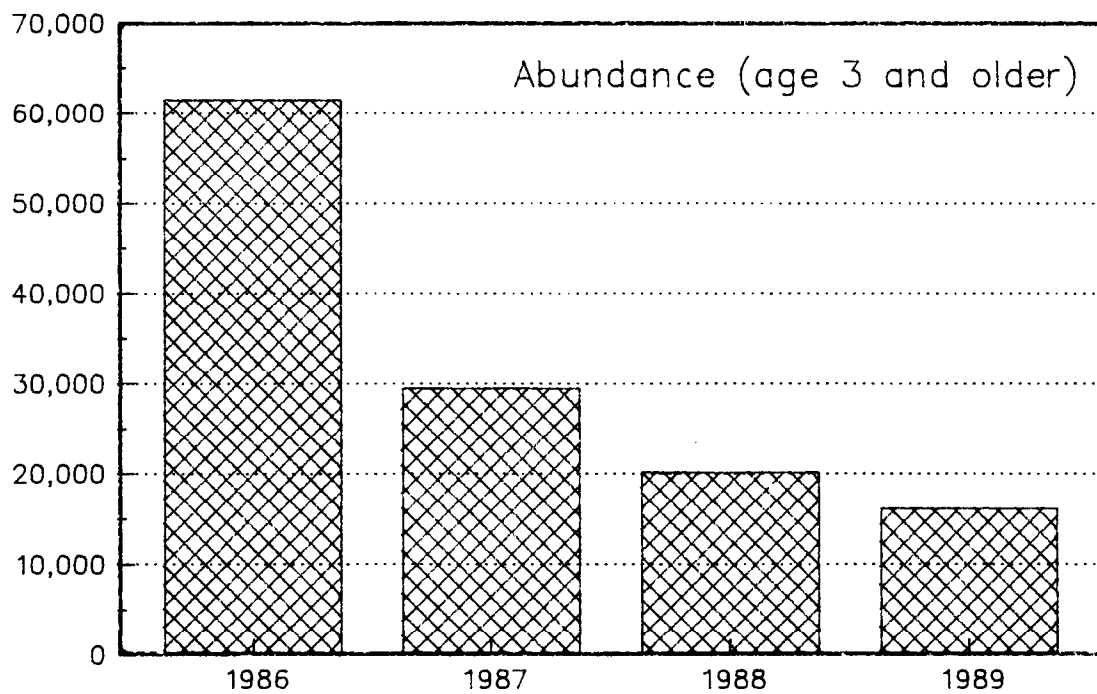


Figure 8. Abundance (A) and survival (B) of Arctic grayling (\geq age 3) in the the lower 152 km of the Chena River, 1986-1989.

instantaneous rates and variance. The recruitment process has been adequately described, but prediction beyond three years requires prediction or stochastic simulation of river discharge during June. If these complications in estimation are overcome, the present regulatory structure can be assessed for its ability to provide protection to the Chena River Arctic grayling stock.

In summary, adequacy of the present regulatory structure cannot be assessed from a long-term standpoint. A short term assessment of the regulations is possible, but requires many assumptions. Although population abundance has declined since the current regulatory structure was imposed, the rate of decline has slowed. Annual survival has increased since the new regulations were imposed in 1987 (Figure 8). Forecast recruitment for the next two years (1990 and 1991) appears to be higher than the previous three years (Table 10). If survival rate has been maximized, then annual recruitment must exceed approximately 7,000 age 3 Arctic grayling for the population to stabilize at 1989 abundance levels. Stabilization of the population at the 1989 level will not maximize the recreational potential of this Arctic grayling stock. Additional years of below replacement level recruitment may necessitate restructuring of regulations and management policies to protect the stock from irreparable damage.

ACKNOWLEDGEMENTS

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APPENDIX A

Appendix A1. Source citations for Federal Aid and Fishery Data Reports used for data summaries, 1955-1958 and 1967-1989.

Year	Type of Data ^a	Source Document
1955	CC	Warner (1959)
1956	CC	Warner (1959)
1957	CC	Warner (1959)
1958	CC	Warner (1959)
1967	AL, CC, POP	Van Hulle (1968)
1968	AL, CC, POP	Roguski and Winslow (1969)
1969	AL, CC, POP	Roguski and Tack (1970)
1970	CC, POP	Tack (1971)
1971	POP	Tack (1972)
1972	CC, POP	Tack (1973)
1973	AL, POP	Tack (1974)
1974	AL, CC, POP	Tack (1975)
1975	AL, CC, POP	Tack (1976)
1976	AL, CC, POP	Hallberg (1977)
1977	AL, CC, POP	Hallberg (1978)
1978	AL, CC, POP	Hallberg (1979)
1979	AL, CC, POP	Hallberg (1980)
1980	AL, CC, POP	Hallberg (1981)
1981	AL, CC, POP	Hallberg (1982)
1982	AL, CC, POP	Holmes (1983)
1983	AL, CC, POP	Holmes (1984)
1984	AL, CC, POP	Holmes (1985)
1985	AL, CC, POP	Holmes et al. (1986)
1986	CC	Clark and Ridder (1987a)
	AL, POP	Clark and Ridder (1987b)
1987	CC	Baker (1988)
1987	AL, POP	Clark and Ridder (1988)
1988	CC	Baker (1989)
	AL, POP	Clark (1989)
1989	CC	Merritt (In press)
	AL, POP	Clark (this report)

^a CC = Creel census estimates;
 AL = age and size composition estimates; and,
 POP = population abundance estimates.

Appendix A2. Chena River study sections used from 1968 to 1985^a.

Section Number	Section Name	River Kilometers	Length in Kilometers
1	River mouth to University Ave.	0-9.6	9.6
2A	University Ave. to Peger Road	9.6-12.8	3.2
2B	Peger Road to Wendell Street	12.8-17.6	4.8
3	Wendell St. to Wainwright Bridge	17.6-23.2	5.6
4	Wainwright Bridge to Badger Slough	23.2-34.4	11.2
5	Badger Slough		26.4
6	Badger Slough to Little Chena R.	34.4-39.2	4.8
7	Little Chena River		98.4
8	Little Chena to Nordale Slough	39.2-49.6	10.4
DS	Nordale Slough to Bluffs	49.6-88.8	39.2
9B	Bluffs to Bailey Bridge	88.8-100.8	12.0
10	Bailey Bridge to Hodgins Slough	100.8-126.4	25.6
11	Hodgins Slough to 90 Mi. Slough	126.4-144.0	17.6
12	90 Mi. Slough to First Bridge	144.0-147.2	3.2
13	First Bridge to Second Bridge	147.2-151.2	4.0
14	Second Bridge to North Fork	151.2-163.2	12.0
15	North Fork of Chena River		56.0
16	East Fork of Chena River		99.2
17	West Fork of Chena River		56.0

^a Taken from Hallberg 1980.

Appendix A3. Summary of population abundance estimates of Arctic grayling (≥ 150 mm FL) in the Chena River, 1968-1989.

Year	Dates	Area ^a	Estimator ^b	Estimate	Confidence ^c
1968	Summer?	2	SN	411/km	393-1,209
	Summer?	6	SN	283/km	228-381
1969	June?	2	SN	596/km	474-850
	June?	6	SN	571/km	439-816
1970	7/02-7/10	2	SN	919/km	690-1,519
	5/26-5/30	6	SN	373/km	346-408
	6/08-7/08	9B	SN	1,005/km	803-1,411
	6/07-7/07	10	SN	1,171/km	876-1,957
1971	8/30-9/03	2A	SN	300/km	192-1,157
	6/02-6/07	2B	SN	1,302/km	958-2,305
	8/30-9/03	2B	SN	2,338/km	1,753-3,897
	6/21-6/24	6	SN	189/km	161-233
1972	6/22-6/26	2A	SN	309/km	236-489
	6/22-6/26	2B	SN	608/km	493-828
	6/19-6/20	6	SN	159/km	124-235
	6/27-6/29	DS	SN	812/km	604-1,393
1973	7/10-7/13	2A	SN	293/km	218-502
	7/03-7/14	2B	SN	424/km	354-545
	7/16-7/17	6	SN	243/km	203-312
	7/18-7/19	DS	SN	500/km	379-806
1974	6/26-6/28	2A	SE	65/km	36-372
	6/25-6/28	2B	SE	488/km	207-1,378
	8/13-8/15	6	SE	100/km	71-164
	7/09-7/11	DS	SE	263/km	221-326
1975	7/10-7/14	6	SE	191/km	114-589
1976	7/19-7/21	2A	SE	258/km	223-307
	7/22-7/24	2B	SE	409/km	323-556
	7/28-7/30	6	SE	163/km	153-175
	8/04-8/06	DS	SE	306/km	285-329
1977	7/05-7/08	2A	SE	318/km	298-343
	7/11-7/14	2B	SE	318/km	280-370
	7/18-7/21	6	SE	173/km	170-177
	7/26-7/30	DS	SE	315/km	283-359
1978	7/14-7/17	2A	SE	69/km	44-156
	7/25-7/28	2B	SE	162/km	148-179
	7/10-7/13	6	SE	226/km	210-243
	8/08-8/11	DS	SE	345/km	333-359

- Continued -

Appendix A3. (page 2 of 2)

Year	Dates	Area ^a	Estimator ^b	Estimate	Confidence ^c
1979	7/01-7/03	2A	SE	57/km	45-76
	6/26-6/30	2B	SE	201/km	188-216
	8/20-8/23	8A	SE	177/km	161-197
	7/17-7/20	DS	SE	193/km	144-288
1980	7/01-7/04	2B	SE	308/km	229-471
	7/14-7/17	8A	SE	190/km	154-248
	7/29-8/01	DS	SE	236/km	200-287
	8/12-8/15	10B	SE	842/km	640-1,234
1981	8/07-8/10	2B	SN	262/km	223-392
	8/03-8/06	8A	SN	224/km	164-309
	8/11-8/14	DS	SN	302/km	174-440
	7/21-7/24	10B	SN	869/km	466-1,778
1982	7/16-7/20	2B	SN	116/km	79-177
	7/13-7/15	8A	SN	87/km	60-132
	7/23-7/27	DS	SN	232/km	113-579
	7/28-7/30	10B	SN	875/km	529-1563
1983	7/13-7/15	2B	SN	216/km	168-265
	7/05-7/07	8A	SN	119/km	81-545
	7/8, 7/11-7/12	DS	SN	209/km	149-303
	7/26-7/28	10B	SN	911/km	647-1,338
1984	7/19-7/21	12	SN	208/km	138-332
	7/16-7/18	2B	SN	211/km	167-268
	7/3, 7/05-7/06	8A	SN	139/km	95-215
	7/09-7/11	DS	SN	179/km	124-273
1985	7/19-7/20	10B	P	493/km	275-1,003
	7/31, 8/02-8/03	12	SN	1,318/km	449-6,592
	7/10-7/17	2B	SN	189/km	92-287
	6/26-7/02	8A	SN	271/km	189-360
1986	7/03-7/08	DS	SN	333/km	234-432
	7/22-7/31	10B	SN	1,156/km	304-3,035
	6/12-6/24	12	SN	1,092/km	552-1,643
	7/07-8/06	WC	EXP	61,581	SE = 26,987
1987	6/27-7/30	WC	EXP+P	31,502	SE = 3,500
1988	6/26-8/04	WC	EXP+P	22,204	SE = 2,092
1989	7/10-8/03	WC	EXP+P	19,028	SE = 1,578

^a Areas are taken from Hallberg (1980); WC = Whole Chena River (lower 152 km).

^b Estimators are: SN = Schnabel; SE = Schumacher-Eschmeyer; P = Petersen (Ricker 1975); EXP = Expanded estimates (Clark and Ridder 1987b); EXP+P = expanded estimates and a Petersen estimate (Clark and Ridder 1988).

^c Confidence is either the 95% confidence interval or the Standard Error (SE) of the estimate.

Appendix A4. Summary of Arctic grayling creel census on the Chena River, 1955-1958, 1967-1970, 1972, and 1974-1989.

Year	Dates	Area	Angler Hours	Harvest	CPUE	Mean Length
1955	ND	Lower Chena	---	---	0.89	226
1956	ND	Lower Chena	---	---	0.95	251
1957	ND	Lower Chena	---	---	0.62	246
1958	ND	Lower Chena	---	---	0.88	226
1967	4/10 to 8/11	Entire Chena	12,885	---	0.32	245
1968	5/01 to 9/02	Entire Chena	10,269	5,643	0.55	251
1969	7/01 to 9/30	Entire Chena	7,998	7,686	0.96	263
1970	5/01 to 5/30 and 7/01 to 8/31	Entire Chena	12,518	6,770	0.54	---
1972	5/25 to 8/27	Lower Chena	13,116	10,099	0.77	---
1974	7/01 to 8/31	Upper Chena	11,680	18,049	1.72	---
1975	6/01 to 8/31	Upper Chena	22,657	14,067	0.62	252
1976	6/01 to 8/31	Upper Chena	10,762	4,161	0.39	230
1977	6/01 to 8/31	Upper Chena	13,563	9,406	0.71	208
1978	5/29 to 8/31	Upper Chena	10,508	6,898	0.65	222
1979	6/01 to 8/31	Upper Chena	12,564	8,544	0.69	240
1980	5/08 to 9/30	Upper Chena	20,827	16,390	0.78	256
1981	5/01 to 8/31	Upper Chena	15,896	13,549	0.80	---
1982	5/01 to 9/15	Upper Chena	20,379	12,603	0.62	248
1983	5/01 to 9/15	Upper Chena	19,018	10,821	0.58	260
1984	5/06 to 9/15	Upper Chena	17,090	9,623	0.59	278
1985	5/08 to 9/05	Upper Chena	10,613	2,367	0.22	273
1986	5/10 to 9/15	Upper Chena	10,716	3,326	0.31	271
1987	5/18 to 9/15	Upper Chena	9,090	1,260	0.14	290
1988	5/14 to 9/13	Upper Chena	11,763	1,583	0.13	287
1989 ^a	5/19 to 9/13	Upper Chena	12,988	2,352	0.18	295

^a Preliminary estimates of effort, harvest, CPUE, and mean length.

Appendix A5. Summary of age composition estimates of Arctic grayling in the Chena River, 1967-1969 and 1973-1989.

Year	Age 0		Age 1		Age 2		Age 3		Age 4		Age 5		Age 6		Age 7		Age 8		Age 9		Age 10		Age 11	
	p ^a	SE ^b	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE
1967	0.10	0.02	0.13	0.02	0.13	0.02	0.06	0.01	0.17	0.02	0.25	0.02	0.11	0.02	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1968	0.09	0.03	0.21	0.04	0.24	0.04	0.25	0.04	0.13	0.03	0.03	0.01	0.05	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1969	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.06	0.38	0.07	0.12	0.05	0.16	0.05	0.06	0.03	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.06	0.02	0.13	0.02	0.61	0.03	0.18	0.03	0.03	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.04	0.01	0.11	0.02	0.12	0.02	0.44	0.03	0.25	0.02	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.13	0.04	0.25	0.05	0.13	0.04	0.26	0.05	0.19	0.04	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.10	0.02	0.24	0.03	0.29	0.03	0.15	0.02	0.09	0.02	0.11	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.06	0.02	0.34	0.03	0.45	0.03	0.08	0.02	0.06	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.15	0.02	0.38	0.03	0.22	0.03	0.21	0.02	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.11	0.02	0.20	0.03	0.45	0.03	0.17	0.03	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.02	0.01	0.12	0.02	0.39	0.03	0.28	0.03	0.13	0.02	0.05	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.16	0.02	0.13	0.02	0.40	0.02	0.12	0.02	0.12	0.02	0.06	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.06	0.01	0.30	0.03	0.11	0.02	0.35	0.03	0.09	0.02	0.04	0.01	0.02	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.01	0.01	0.07	0.01	0.11	0.01	0.45	0.02	0.08	0.01	0.17	0.02	0.06	0.01	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.19	0.02	0.07	0.01	0.12	0.02	0.41	0.02	0.08	0.01	0.09	0.01	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.02	0.00	0.16	0.01	0.11	0.01	0.14	0.01	0.32	0.01	0.10	0.01	0.10	0.01	0.04	0.00	0.02	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.01	0.07	0.01	0.09	0.01	0.13	0.01	0.04	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.05	0.01	0.08	0.01	0.60	0.03	0.07	0.01	0.05	0.01	0.10	0.02	0.02	0.01	0.02	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.09	0.02	0.15	0.02	0.12	0.02	0.42	0.04	0.07	0.01	0.06	0.01	0.07	0.01	0.02	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.15	0.02	0.23	0.03	0.14	0.02	0.14	0.02	0.22	0.03	0.06	0.01	0.04	0.01	0.03	0.01	0.00	0.00	0.00	0.00

^a p = the proportion of the sample at age.

^b SE = the standard error of p.

Appendix A6. Summary of mean length at age estimates of Arctic grayling from the Chena River, 1967-1969 and 1973-1989.

Year	Age 0 n ^a FL ^b		Age 1 n FL		Age 2 n FL		Age 3 n FL		Age 4 n FL		Age 5 n FL		Age 6 n FL		Age 7 n FL		Age 8 n FL		Age 9 n FL		Age 10 n FL		Age 11 n FL	
1967	30	25	41	135	41	186	17	243	51	272	77	293	32	321	15	335	0	---	0	---	0	---	0	---
1968	10	73	24	103	28	150	29	214	15	255	3	289	6	304	2	372	0	---	0	---	0	---	0	---
1969	0	---	0	---	0	---	11	191	19	236	6	273	8	304	3	317	3	356	0	---	0	---	0	---
1973	0	---	11	111	25	167	121	194	36	215	6	279	0	---	1	310	0	---	0	---	0	---	0	---
1974	0	---	12	130	32	169	37	199	133	217	76	236	12	259	1	315	0	---	0	---	0	---	0	---
1975	0	---	0	---	12	171	22	200	12	229	23	238	17	258	2	275	1	320	0	---	0	---	0	---
1976	0	---	26	144	61	175	74	194	39	221	24	249	28	270	4	308	0	---	0	---	0	---	0	---
1977	0	---	14	112	77	176	102	208	19	245	13	263	4	299	0	---	0	---	0	---	0	---	0	---
1978	0	---	39	128	102	167	59	206	56	230	9	256	2	290	1	325	0	---	0	---	0	---	0	---
1979	0	---	25	107	44	165	99	197	38	236	11	266	1	310	0	---	0	---	0	---	0	---	0	---
1980	0	---	4	114	31	154	97	198	71	231	33	259	12	292	3	327	0	---	0	---	0	---	0	---
1981	0	---	61	112	48	162	152	187	46	215	47	240	22	268	5	287	3	310	0	---	0	---	0	---
1982	0	---	19	105	88	137	34	190	105	215	26	251	11	279	7	305	6	337	0	---	0	---	0	---
1983	6	62	33	114	53	151	215	177	38	216	83	239	29	273	13	307	7	338	0	---	0	---	0	---
1984	0	---	82	97	32	153	54	182	179	213	36	226	40	257	7	275	6	321	0	---	0	---	0	---
1985	0	---	42	108	300	141	203	188	267	215	609	233	182	285	188	285	80	308	30	377	2	377	0	---
1986	0	---	40	109	104	164	755	184	79	220	110	251	153	270	42	301	22	318	5	330	1	346	0	---
1987	0	---	0	---	54	160	92	204	691	228	115	274	76	292	184	309	30	324	31	338	2	353	0	---
1988	0	---	7	108	135	172	238	216	181	239	707	260	118	288	95	313	110	325	35	347	7	337	2	374
1989	0	---	17	123	285	156	295	215	205	254	245	272	423	285	112	314	73	329	54	347	5	372		
Average	40		113		157		190		224		245		271		299		316		334		361		374	

^a n = sample size.

^b FL = the arithmetic mean fork length in millimeters.

Appendix A7. Summary of Relative Stock Density (RSD) indices of Arctic grayling (≥ 150 mm FL) captured by electrofishing from the Chena River, 1972-1989.

	RSD Category ^a				
	Stock	Quality	Preferred	Memorable	Trophy
<u>1972 (2A, 2B, 6, DS) - 6/19-6/22^b</u>					
Sample size	1,392	42	3	0	0
RSD	0.97	0.03	<0.01	0.00	0.00
Standard Error	0.01	<0.01	<0.01	0.00	0.00
<u>1973 (2A, 2B, 6, DS) - 7/3-7/19</u>					
Sample size	176	7	0	0	0
RSD	0.96	0.04	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00
<u>1974 (2A, 2B, 6, DS) - 6/25-8/15</u>					
Sample size	889	58	0	0	0
RSD	0.94	0.06	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00
<u>1975 (6) - 7/10-7/14</u>					
Sample size	76	13	0	0	0
RSD	0.85	0.15	0.00	0.00	0.00
Standard Error	0.04	0.04	0.00	0.00	0.00
<u>1976 (2A, 2B, 6, DS) - 7/19-8/6</u>					
Sample size	613	59	1	0	0
RSD	0.91	0.09	<0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
<u>1977 (2A, 2B, 6, DS) - 7/5-7/30</u>					
Sample size	916	30	0	0	0
RSD	0.967	0.03	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00
<u>1978 (2A, 2B, 6, DS) - 7/10-8/11</u>					
Sample size	841	20	0	0	0
RSD	0.98	0.02	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00

- Continued -

Appendix A7. (page 2 of 3)

	RSD Category ^a				
	Stock	Quality	Preferred	Memorable	Trophy
<u>1979 (2A, 2B, 8A, DS) - 6/26-8/23</u>					
Sample size	802	13	0	0	0
RSD	0.98	0.02	0.00	0.00	0.00
Standard Error	<0.01	<0.01	0.00	0.00	0.00
<u>1980 (2B, 8A, DS, 10B) - 7/1-8/15</u>					
Sample size	1,260	53	2	0	0
RSD	0.96	0.04	<0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
<u>1981 (2B, 8A, DS, 10B) - 7/21-8/14</u>					
Sample size	1,247	42	1	0	0
RSD	0.97	0.03	<0.01	0.00	0.00
Standard Error	<0.01	<0.01	<0.01	0.00	0.00
<u>1982 (2B, 8A, DS, 10B) - 7/13-7/30</u>					
Sample size	919	76	5	0	0
RSD	0.92	0.08	0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
<u>1983 (2B, 8A, DS, 10B, 12) - 7/5-7/28</u>					
Sample size	1,560	152	10	0	0
RSD	0.91	0.09	0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
<u>1984 (2B, 8A, DS, 10B, 12) - 7/3-8/3</u>					
Sample size	1,349	74	4	0	0
RSD	0.95	0.05	<0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
<u>1985 (2B, 8A, DS, 10B, 12) - 6/12-7/31</u>					
Sample size ^c	ND	ND	ND	ND	ND
RSD	---	---	---	---	---
Standard Error	---	---	---	---	---

- Continued -

Appendix A7. (page 3 of 3)

	RSD Category ^a				
	Stock	Quality	Preferred	Memorable	Trophy
<u>1986 (lower 152 km) - 7/7-8/6</u>					
Sample size	1,268	160	29	0	0
RSD	0.87	0.11	0.02	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
<u>1987 (lower 152 km) - 6/27-7/30</u>					
Sample size	1,678	693	154	0	0
RSD	0.67	0.27	0.06	0.00	0.00
Adjusted RSD ^d	0.78	0.19	0.03	0.00	0.00
Standard Error ^e	0.04	0.04	0.01	0.00	0.00
<u>1988 (lower 152 km) - 6/26-8/4</u>					
Sample size ^f	1,855	1,242	217	0	0
RSD	0.63	0.32	0.05	0.00	0.00
Standard Error	0.04	0.03	0.01	0.00	0.00
<u>1989 (lower 152 km) - 7/10-8/3</u>					
Sample size ^f	1,363	1,340	184	0	0
RSD	0.47	0.46	0.06	0.00	0.00
Adjusted RSD ^d	0.57	0.38	0.05	0.00	0.00
Standard Error ^e	0.04	0.04	0.01	0.00	0.00

^a Minimum lengths for RSD categories are (Gabelhouse 1984):

Stock - 150 mm FL; Quality - 270 mm FL; Preferred - 340 mm FL;

Memorable - 450 mm FL; and, Trophy - 560 mm FL.

^b Year (sections sampled (taken from Hallberg 1980)) - sampling dates.

^c Lengths were taken in 1985, but not reported in Holmes et al. (1986).

^d RSD was adjusted to correct for bias due to the electrofishing boat (Clark and Ridder 1988).

^e Standard error is for adjusted RSD only.

^f Sample sizes do not correspond to RSD proportions because RSD proportions are weighted by abundance estimates in a stratified design (Clark 1989) and RSD is adjusted to correct for bias due to the electrofishing boat (Clark and Ridder 1988).

Appendix A8. Parameter estimates and standard errors of the von Bertalanffy growth model^a for Arctic grayling from the Chena River, 1986-1988.

Parameter	Estimate	Standard Error
L_{∞} ^b	538	21
K ^c	0.10	0.01
t_0 ^d	-1.72	0.11
$Corr(L_{\infty}, K)$ ^e	-0.99	---
$Corr(L_{\infty}, t_0)$	-0.91	---
$Corr(K, t_0)$	0.95	---
Sample size	4,301	

^a The form of the von Bertalanffy growth model (Ricker 1975) is as follows: $l_t = L_{\infty} (1 - \exp(-K (t - t_0)))$. The parameters of this model were estimated with data collected during 1986 through 1988. This model was fitted to the data by nonlinear regression (SAS 1985) utilizing the Marquardt compromise (Marquardt 1963). The range of ages used to model growth was age 1 through age 11.

^b L_{∞} is the length a fish would achieve if it continued to live and grow indefinitely (Ricker 1975).

^c K is a constant that determines the rate of increase of growth increments (Ricker 1975).

^d t_0 represents the hypothetical age at which a fish would have zero length (Ricker 1975).

^e $Corr(x,y)$ is the correlation of parameter estimates x and y .

